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(54) Title: PREPARING POLYESTER FINE FILAMENTS

(57) Abstract

Polyester fine filaments having excellent mechanical quality and uniformity, and preferably with a balance of good dyeability and shrinkage, are prepared by a simplified direct spin-orientation process by selection of polymer viscosity and spinning conditions.

TITLE

Preparing Polyester Fine Filaments

This invention concerns improvements in, and
relating to, polyester fine filaments and their
5   manufacture and use.

Historically, synthetic fibers for use in
apparel, including polyester fibers, have generally
been supplied to the textile industry for use in
fabrics and garments with the object of more or less
10   duplicating and/or improving on natural fibers. For
many years, commercial synthetic textile filaments,
such as were made and used for apparel, were mostly of
deniers per filament (dpf) in a similar range to those
of the commoner natural fibers; i.e., cotton and wool.
15   More recently, however, polyester filaments have been
available commercially in a range of dpf similar to
that of natural silk, i.e. of the order of 1 dpf, and
even in subdeniers, i.e., less than about 1 dpf,
despite the increased cost. Various reasons have been
20   given for the recent commercial interest in such lower
dpfs, such as about 1 dpf, or even subdeniers.

Much has been written recently about this
increasing interest in fine denier polyester filaments.
Very little technical detail has, however, been
25   published about any difficulties in spinning (i.e.,
extrusion and winding) techniques that have been used,
or even would be desirable, for manufacturing such fine
filaments, although it has been well understood by
those skilled in the art that conventional preparation
30   and handling techniques could not be used for such fine
filaments. For instance, in Textile Month, June 1990,
pages 40-46, three approaches are discussed for making
microfibers; namely, 1) conventional spinning to fine

deniers, 2) splitting bicomponent fibers (of higher deniers), and 3) dissolving away a component from bicomponent fibers of higher denier. It will be understood that the 2nd and 3rd approaches involve

5   bicomponent spinning to form filaments first of higher denier, and processing such spun higher denier filaments to obtain the filaments of reduced denier; such processing techniques are not the subject of the present invention.

10   The present invention is concerned with the preparation of fine filaments by a novel direct spinning/winding process, in contrast with a process of first spinning and winding up bicomponent filaments of higher denier which then must be further processed to

15   obtain the reduced fine denier filaments that are desired for use in textiles. Another 2-stage possibility of manufacturing filaments of reduced denier is to spin filaments of greater than one denier, and then, draw the filaments after the spinning

20   operation, but this possibility has important disadvantages that have been discussed in the art; on the one hand, there are practical limitations to the amount of draw that can be effected; there are also product disadvantages in the properties of drawn yarns,

25   as contrasted with direct spin-oriented yarns; and the cost of such processing (i.e., drawing) has to be considered, especially when the drawing is performed as a separate operation, after first packaging the spun filaments, such as single yarn or warp drawing. Such

30   drawing proposals may have involved conventional drawing techniques, or may have involved other techniques, e.g., aerodynamic effects or reheating the filaments after they have been solidified, but still advancing under sufficient tension to draw (sometimes

35   referred to as space-drawing, if performed without

godets of differential speeds). Some direct spinning
processes that have been proposed have relied on use of
specific polymer compositions, for instance specific
viscosities, that have disadvantages, so it would be
desirable to use a process that does not require use of
special viscosities or other special compositional
aspects.

To summarize, previous polyester filament
manufacturing techniques that have been disclosed in
the art have not been specifically directed to and have
not been suitable in practice for producing fine denier
polyester filaments by a simple direct spinning/winding
operation, or have involved limitations and
disadvantages. So it has been desirable to provide
such a direct spinning process for manufacturing fine
polyester filaments of the desired dpf and properties
without such disadvantages. The present invention
solves this problem. The filaments of the invention
are "spin-oriented", the significance of which is
discussed in the art and hereinafter.

Commercial polyester filaments were made
initially by "split" processes that involved a separate
drawing stage after spinning and winding undrawn
filaments. In the 1950's, Hebeler suggested in U. S.
Patents Nos. 2,604,667 and 2,604,689, the possibilities
of high speed spinning of polyester melts. In the
1970's, high speed spinning of polyester melts, as
described by Petrille in U. S. Patent No. 3,771,307 and
by Piazza and Reese in U. S. Patent No. 3,772,872, were
made the basis of a process for preparing spin-oriented
yarns that have been used as draw-texturing feed yarns.
High speed spinning of polyester melts has also been
the basis of other processes that were first disclosed
in the 1970's, such as Knox in U. S. Patent No.
4,156,071, and Frankfort and Knox in U. S. Patent Nos.

4,134,882, and 4,195,051.

The art discloses fundamental differences in fine structure and properties between filaments that are spin-oriented, indicating orientation of the polyester molecules obtained from the (high speed) spinning, and drawn filaments, indicating orientation derived from drawing of the filaments as an entirely separate process, after winding the spun filaments, or even as a continuous process, before winding, but after cooling the melt to form solid filaments before drawing such filaments.

An object of the present invention is to provide fine filaments that have the characteristics of being spin-oriented, because of the advantageous properties that are provided by this characteristic.

Several aspects and embodiments are provided according to the present invention as follows:

1) a process for preparing spin-oriented polyester fine filaments;

2) spin-oriented polyester fine filaments with deniers about 1 or less, having enhanced mechanical quality and denier uniformity making these filaments especially suitable for high speed textile processing;

3) spin-oriented polyester fine filaments, especially suitable for use as draw feed yarns in high speed texturing, crimping, and warping processes;

4) spin-oriented polyester fine filaments, especially suitable for use as direct-use textile yarns, without need for additional draw or heat treatments, in critically dyed flat woven and knit

fabrics; for use as feed yarns for air-jet texturing
and stuffer-box crimping, wherein no draw is required;
and may be uniformly cold drawn, if desired, to prepare
warp yarns of higher shrinkage with dye uniformity

5   suitable for critically dyed end-uses;

        5) drawn spin-oriented polyester fine
filaments, especially suitable for use as textile yarns
in critically dyed flat woven and knit fabrics; and
processes for preparing these fine drawn fine filament

10   yarns;

        6) bulked polyester fine filament yarns
capable of being dyed uniformly under atmospheric
conditions without the use of carriers; and a process
for preparing these bulked fine filament yarns;

15   7) mixed filament yarns, wherein the fine
filaments are of this invention; and especially mixed
filament yarns, wherein, all filaments are of this
invention, but differ in denier, cross-section, and/or
shrinkage potential.

20   In particular according to the present
invention, the following are provided:

        A process for preparing spin-oriented
polyester fine filaments, wherein,

        (i) the polyester polymer is selected to have

25   a relative viscosity (LRV) in the range of about 13 to
about 23, a zero-shear melting point (T_M^o) in the range
of about 240°C to about 265°C, and a glass transition
temperature (T_g) in the range of about 40°C to about
80°C;

30   (ii) said polyester is melted and heated to a
temperature (T_p) in the range of about 25°C to about

55°C, preferably in the range of about 30°C to about
50°C, above the apparent polymer melting point $(T_M)a$;

(iii) the resulting melt is filtered
sufficiently rapidly that the residence time (t_r) at
5   polymer melt temperature (T_p) is less than about 4
minutes;

(iv) the filtered melt is extruded through a
spinneret capillary at a mass flow rate (w) in the
range about 0.07 to about 0.7 grams per minute (g/min),
10   and the capillary is selected to have a cross-sectional
area (A_c) in the range about 125×10^{-6} cm^2 (19.4 mils^2)
to about 1250×10^{-6} cm^2 (194 mils^2) preferably in the
range of about 125×10^{-6} cm^2 (19.4 mils^2) to about
750×10^{-6} cm^2 (116.3 mils^2) and a length (L) and
15   diameter (D_{RND}) such that the (L/D_{RND})-ratio is at
least about 1.25 and preferably less than about 6, and
especially less than about 4;

(v) protecting the extruded melt from direct
cooling as it emerges from the spinneret capillary over
20   a distance (L_{DQ}) of at least about 2 cm and less than
about $(12dpf^{\frac{1}{2}})$cm, where dpf is the denier per filament
of the spin-oriented polyester fine filament,
preferably in the range of about 1 to about 0.2 dpf,
and especially in the range of about 0.8 to about 0.2
25   dpf; and desireably an average along-end denier spread
(DS) less than about 4%, and preferably less than about
3%, and especially less than about 2%;

(vi) cooling the attenuating spinline to
below the polymer glass-transition temperature (T_g),
30   preferably by radially directed air having a
temperature (T_a) less than about the polymer T_g and a
velocity (V_a) in the range of about 10 to about 30
meters per minute (m/min);

(vii) attenuating to an apparent spinline
strain (ε_a) in the range of about 5.7 to about 7.6, and
to an apparent internal spinline stress (σ_a) in the
range of about 0.045 to about 0.195 grams per denier
(g/d), preferably in the range of about 0.045 to about
0.105 g/d for preparing filaments especially suitable
for draw feed yarns, characterized by a tenacity-at-7%-
elongation (T_7) in the range of about 0.5 to about 1
g/d; and to an apparent internal spinline stress (σ_a)
preferably in the range of about 0.105 to about 0.195
g/d for preparing filaments especially suitable for
direct-use yarns, characterized by a tenacity-at-7%-
elongation (T_7) in the range of about 1 to about 1.75
g/d;

(viii) converging the cooled and attenuated
filaments into a multifilament bundle by use of a low
friction surface at a distance (L_c) in the range about
50 cm to about 140 cm, preferably in the range of about
50 cm to about $(50+90dpf^{\frac{1}{2}})$cm;

(ix) winding up the multifilament bundle at a
withdrawal speed (V) in the range of about 2 to about 6
kilometers per minute (km/min), preferably in the range
of about 2 to about 5 km/min, and especially in the
range of about 2.5 to about 5 km/min;

Also, according the present invention the
following spin-oriented polyester fine filaments, and
products there from, are provided:

Spin-oriented polyester fine filaments of
denier per filament (dpf) about 1 or less, preferably
in the range of about 0.8 to about 0.2 dpf, wherein,
said polyester is characterized by having a relative
viscosity (LRV) in the range of about 13 to about 23, a
zero-shear polymer melting point (T_M^O) in the range of

about 240°C to about 265°C, and a glass-transition
temperature (T_g) in the range of about 40°C to about
80°C; and said fine filaments are further characterized
by:

5   (i) boil-off shrinkage (S) less than about
the maximum shrinkage potential (S_m), wherein S_m =
[(550-E_B)/6.5],% and the percent elongation-to-break
(E_B) is in the range about 40% to about 160%;

           (ii) maximum shrinkage tension, (ST_{max}), in
10   the range about 0.05 to about 0.2 g/d, with a peak
temperature T(ST_{max}), in the range about 5°C to about
30°C above the polymer glass-transition temperature
(T_g);

           (iii) a tenacity-at-7%-elongation (T_7) in the
15   range of about 0.5 to about 1.75 g/d, and such that the
[(T_B)$_n$/T_7]-ratio is of at least about (5/T_7) and
preferably at least about (6/T_7); wherein, (T_B)$_n$ is the
tenacity-at-break normalized to a reference LRV of 20.8
and % delusterant (such as TiO_2) of 0%;

20   (iv) desireably an average along-end denier
spread (DS) of less than about 4%, preferably less than
about 3%, and especially less than about 2%.

           Spin-oriented fine filaments, especially
suitable for use as draw feed yarns (DFY),
25   characterized by a boil-off shrinkage (S) at least
about 12%, an elongation-at-break (E_B) in the range
about 80% to about 160%, a tenacity-at-7%-elongation
(T_7) in the range about 0.5 to about 1 g/d.

           Spin-oriented fine filaments, especially
30   suitable for use as direct-use yarns (DUY),
characterized by a shrinkage differential (ΔS = DHS -
S) less than about +2%, wherein, boil-off shrinkage (S)

and dry heat shrinkage (DHS) are in the range of about
2% to about 12%, such that the filament denier after
boil-off shrinkage, dpf(ABO), is about 1 or less and
preferably in the range of about 1 to about 0.2 dpf,
and more preferably in the range of about 0.8 to about
0.2 dpf; a tenacity-at-7%-elongation (T_7) in the range
of about 1 to about 1.75 g/d; an elongation-at-break
(E_B) in the range of about 40% to about 90%, and a
post-yield modulus (M_{py}) in the range of about 2 to
about 12 g/d;

Spin-oriented fine filaments having the
capability of being uniformly cold drawn, characterized
by a shrinkage differential ($\Delta S = DHS - S$) less than
about +2%, wherein, boil-off shrinkage (S) and dry heat
shrinkage (DHS) are in the range of about 2% to about
12%, an onset of cold crystallization, T_{cc}(DSC), of
less than about 105°C and an instantaneous tensile
modulus (M_i) at least about 0.

Drawn spin-oriented polyester fine filaments
with deniers after boil-off shrinkage, dpf(ABO), in the
range of about 1 or less, preferably in the range of
about 0.8 to about 0.2 dpf, wherein, said drawn
filaments are further characterized by:

(i) boil-off shrinkage (S) and dry heat
shrinkage (DHS) in the range of 2% to about 12%;

(ii) a tenacity-at-7%-elongation (T_7) of at
least about 1 g/d, such that the $[(T_B)_n/T_7]$-ratio is at
least about $(5/T_7)$; preferably at least about $(6/T_7)$,
wherein, $(T_B)_n$ is the tenacity-at-break normalized to a
reference LRV of 20.8 and percent delusterant (such as
TiO_2) of 0%; and an elongation-at-break (E_B) in the
range of about 15% to about 55%;

(iii) a post-yield modulus (M_{py}), preferably

in the range about 5 to about 25 g/d;

(iv) desireably an average denier spread (DS) less than about 4%, preferably less than about 3%, especially less than about 2%.

5   Bulked spin-oriented polyester fine filaments of denier after boil-off shrinkage, dpf (ABO), in the range of about 1 to about 0.2 dpf, preferably 0.8 to about 0.2 dpf, wherein, said bulked filaments are further characterized by a boil-off shrinkage (S) and
10   dry heat shrinkage (DHS) in the range 2% to about 12%, an elongation-at-break (E_B) in the of range about 15% to about 55%, a tenacity-at-7%-elongation (T_7) at least about 1 g/d, and preferably with a post-yield modulus (M_{py}) in the range about 5 to about 25 g/d and a
15   relative disperse dye rate (RDDR), normalized to 1 dpf, of at least about 0.1.

Mixed filament yarns, wherein the fine filaments are of this invention; and especially mixed filament yarns, wherein, all filaments are of this
20   invention, but differ in denier, cross-section, and/or shrinkage potential.

Preferred such spin-oriented, bulked and drawn flat filaments are capable of being dyed with cationic dyestuffs, on account of containing in the
25   range of about 1 to about 3 mole % of ethylene-5-M-sulfo-isophthalate structural units, where M is an alkali metal cation, such sodium or lithium.

Especially preferred such spin-oriented, bulked, and drawn flat filaments capable of being
30   disperse dyed uniformly under atmospheric conditions without carriers, are characterized by a dynamic loss modulus peak temperature $T(E''_{max})$ of less than about 115°C, preferably less than about 110°C; and are of

polyester polymer, essentially poly(ethylene
terephthalate), composed of first alternating
hydrocarbolenedioxy structural units A,
$[-O-C_2H_4-O-]$, and hydrocarbolenedicarbonyl structural

5   units B, $[-C(O)-C_6H_4-C(O)-]$, modified with minor
amounts of other hydrocarbolenedioxy structural units A
and/or hydrocarbolenedicarbonyl structural units B,
that are different from the first structural units,
such as to provide a polyester polymer with a zero-

10   shear melting point (T_M^O) in the range about 240°C to
about 265°C and a glass-transition temperature (T_g) in
the range of about 40°C to about 80°C.

        The filaments of the present invention may be
nonround for enhanced tactile and visual aesthetics,

15   and comfort, where said nonround filaments have a shape
factor (SF) at least about 1.25, wherein the shape
factor (SF) is defined by the ratio of the measured
filament parameter (P_M) and the calculated parameter
(P_{RND}) for a round filament of equivalent cross-

20   sectional area. Hollow filaments may be spun via post-
coalescence from segmented spinneret capillary orifices
to provide lighter weight fabrics with greater bulk and
filament bending modulus for improved fabric drape.

        Further aspects and embodiments of the

25   invention will appear herein.

        FIG. 1 is a graphical representation of
spinline velocity (V) plotted versus distance (x) where
the spin speed increases from the velocity at extrusion
(V_O) to the final (withdrawal) velocity after having

30   completed attenuation (typically measured downstream at
the point of convergence, V_C); wherein, the apparent
internal spinline stress (σ_a) is taken as being
proportional to the product of the spinline viscosity
at the neck point $(\eta)_N$, (i.e., herein found to be

approximately proportional to about the ratio LRV/T_p^6,
where T_p is expressed in °C),and the velocity gradient
at the neck point (dV/dx), (herein found to be
approximately proportional to about V^2/dpf, especially
over the spin speed range of about 2 to 4 km/min and
proportional to about $V^{3/2}/dpf$ at higher spin speeds,
e.g., in the range of about 4 to 6 km/min). The spin
line temperature is also plotted versus spinline
distance (x) and is observed to decrease uniformly with
distance as compared to the sharp rise in spinline
velocity at the neck point.

FIG. 2 is a graphical representation of the
birefringence (Δ_n) of the spin-oriented filaments
versus the apparent internal spinline stress $(\sigma)_a$;
wherein the slope is referred to as the "stress-optical
coefficient, SOC" and Lines A, B, and C have SOC values
of 0.75, 0.71, and 0.645 $(g/d)^{-1}$, respectively; with an
average SOC of about 0.7; and wherein Lines A and C are
typical relationships found in literature for 2GT
polyester. The values of the apparent internal
spinline stress (σ_a) agree well with values found in
literature.

FIG. 3 is a graphical representation of the
tenacity-at-7%-elongation (T_7) of the spin-oriented
filaments versus the apparent internal spinline stress
(σ_a). The near linear relationship of birefringence
(Δ_n) and T_7 versus the apparent internal spinline
stress (σ_a), as shown in FIGS. 2 and 3, permits the use
of T_7 as a useful parameter being representative of the
filament average orientation. Birefringence (Δ_n) is
typically very difficult structural parameter to
measure for fine filaments with deniers less than 1.

FIG. 4 is a graphical representation of the
preferred values of the apparent internal spinline

stress (σ_a) and the spin-oriented filament yarn
tenacity-at-7%-elongation (T_7) plotted versus the spin
line extension ratio E_R (= V/V_o) on a natural logarithm
scale (where E_R-values of 200 and 2000, for example are
expressed on the x-axis as 0.2 and 2; i.e., $E_R/1000$);
wherein the natural logarithm $\ln(E_R)$ is called herein
as the apparent spinline strain (ε_a), where V is the
final (withdrawal) spinline velocity and V_o is the
capillary extrusion velocity. The process of the
invention is described by the enclosed region ADLI with
region ADHE (II) preferred for preparing direct-use
filaments and region EHLI (I) preferred for preparing
draw feed yarns. Especially preferred processes are
represented by regions BCGF and FGKI.

        FIG. 5 is a representative Instron load-
extension curve showing the graphical calculation of
the "secant" post-yield modulus (M_{py}) calculated from
the tenacity-at-7%-elongation (T_7), denoted by point C,
and from the tenacity-at-20%-elongation (T_{20}), denoted
by point A, and defined by the expression
$(1.07T_7-1.2T_{20})/0.13$; and compares the "secant" M_{py}
(herein denoted as tan β to that of the "tangential"
M_{py} (herein denoted as tan α, i.e., slope of line
segment AB). For yarns which have an instantaneous
modulus M_i (= d(stress)/d(elongation) greater than
about 0, the value of tan β is about the same as tan α.

        FIG. 6 is a graphical representation of the
secant M_{py} (tan β in FIG. 5) versus biref.ingence (Δ_n)
of spin-oriented filaments. For yarns wherein tan α is
essentially equal to tan β, the post-yield modulus
(M_{py}) becomes a useful measure of molecular
orientation.

        FIG. 7 is a graphical representation of the
Relative Disperse Dye Rate (RDDR), as normalized to 1

dpf, versus the average filament birefringence (Δ_n).

FIG. 8 is a graphical representation of the filament amorphous free-volume of the fiber ($V_{f,am}$, as defined herein after), versus the peak temperature of the fiber dynamic loss modulus, $T(E''_{max})$, taken herein as a measure of the glass transition temperature which is typically 20°C to about 50°C above the T_g of the polymer. A decreasing $T(E''max)$ value corresponds to greater amorphous free-volume ($V_{f,am}$), and hence to improved dyeability, as measured herein by a Relative Disperse Dye Rate (RDDR) value (normalized to 1 dpf) of at least about 0.1.

FIG. 9 is a graphical representation of the filament density (ρ) versus birefringence (Δ_n); wherein the diagonal lines represent combinations of density (ρ) and (Δ_n) of increasing fractional amorphous orientation (f_a), used in the calculation of the free-volume $V_{f,am}$ depicted in FIG. 8.

FIG. 10 is a representative Differential Scanning Calorimetry (DSC) spectrum showing the thermal transitions corresponding to the glass-transition temperature (T_g), onset of "cold" crystallization T_{cc}(DSC) and the zero-shear melting point T_M of the fiber, which is higher than the zero-shear melting point T_M^o of the polymer due to the effect of orientation and crystallinity of the fiber melting point. To measure the zero-shear melting point (T_M^o) of the polymer, a second DSC heating of the previous melted DSC fiber sample is made to provide the DSC spectrum of the polymer rather than the fiber was extruded.

FIG. 11 is a representative shrinkage tension (ST)-temperature spectrum for the spin-oriented fine

polymer filaments of the invention showing the maximum
shrinkage tension $ST_{(max)}$, peak temperature $T(ST_{max})$
and the preferred "heat set" temperature T_{set} below
which heat setting does not appreciably adversely
5   affect dye ability.

FIG. 12 are representative tenacity (T = load
(gms)/original denier) versus percent elongation curves
for a typical draw feed yarn of the invention (curve
C); for a typical direct-use yarn of this invention
10   (curve B); and for the preferred direct-use yarns of
the invention after relaxed heat treatment (Curve A);
i.e, akin to after dyeing.

FIG. 13 is a graphical representation of the
preferred values for the tenacity-at-break $(T_B)_n$,
15   normalized for the affects of LRV and percent
delusterant (such as TiO_2), plotted as the $(T_B)_n/T_7$-
ratio versus the reciprocal of the T_7 (i.e., versus
$1/T_7$); wherein, Curve A: $[(T_B)_n/T_7] = (5/T_7)$; and curve
B: $[(T_B)_n/T_7] = (6/T_7)$.

20   FIG. 14 is a plot of the ratio, $T_7/(V^2/dpf)$
versus the product of the number of filaments per yarn
extrusion bundle ($\#_C$) and the ratio, $(D_{ref}/D_{sprt})^2$,
where D_{ref} and D_{sprt} are the diameters of a reference
spinneret (e.g., about 75 cm) and the test spinneret,
25   respectively. The slope "n" from a ln-ln plot is found
to be about negative 0.7 (-0.7); that is, the tenacity-
at-7%-elongation (T_7) is found to vary proportionally
to (V^2/dpf) and to $[(\#_C)(D_{ref}/D_{sprt})^2]^{-0.7}$; that is,
the tenacity-at-7%-elongation (T_7) decreases
30   approximately linearly with an increase in the filament
extrusion density to the power of plus 0.7 (+0.7); and
thereby the filament extrusion density may be used to
as a process parameter to spin finer denier filaments
at higher spinning speeds (V). At higher spin speeds,

e.g., in the range of about 4 to 6 km/min, it is found
that the apparent spinline stress increases less
rapidly with spin speed (V); i.e., is found to be
proportional to (V$^{3/2}$/dpf).

5   The polyester polymer used for preparing
spin-oriented filaments of the invention is selected to
have a relative viscosity (LRV) in the range about 13
to about 23, a zero-shear melting point (T$_M$^{o}) in the
range about 240°C to about 265°C; and a glass-
10   transition temperature (T$_g$) in the range about 40°C to
about 80°C (wherein T$_M$^{o} and T$_g$ are measured from the
second DSC heating cycle under nitrogen gas at a
heating rate of 20°C per minute). The said polyester
polymer is a linear condensation polymer composed of
15   alternating A and B structural units, where, A is a
hydrocarbolenedioxy unit of the form [-O-R'-O-] and B
is a hydrocarbolenedicarbonyl unit of the form
[-C(O)-R"-C(O)-], wherein, R' is primarily [-C$_2$H$_4$-], as
in the ethylenedioxy (glycol) unit [-O-C$_2$H$_2$-O-], and R"
20   is primarily [-C$_6$H$_4$-], as in the 1,4-benzenedicarbonyl
unit [-C(O)-C$_6$H$_4$-C(O)-], such to provide, for example,
at least about 85 percent of the recurring structural
units as ethylene terephthalate,
[-O-C$_2$H$_4$-O-C(O)-C$_6$H$_4$-C(O)-].

25   Suitable poly(ethylene terephthalate), herein
denoted as PET or 2GT, based polymer may be formed by
the DMT-process as described by H. Ludwig in his book
"Polyester Fibers, Chemistry and Technology", John
Wiley and Sons Limited (1971), and by the TPA-process
30   as described in Edging U. S. Patent No. 4,110,316.
Included are also copolyesters in which, for example,
up to about 15 percent of the hydrocarbolenedioxy
and/or hydrocarbolenedicarbonyl units are replaced with
different hydrocarbolenedioxy and
35   hydrocarbolenedicarbonyl units to provide enhanced low

temperature disperse dyeability, comfort, and aesthetic properties. Suitable replacement units may be found in Most U. S. Patent No. 4,444,710 (Example VI), Pacofsky U. S. Patent No. 3,748,844 (Col. 4), and Hancock, et

5 al. U. S. Patent No. 4,639,347 (Col. 3).

The polyester polymer may also be modified with ionic dye sites, such as ethylene-5-M-sulfo-isophthalate residues, where M is an alkali metal cation, such as sodium or lithium; for example, in the

10 range of 1 to about 3 mole percent ethylene-5-sodium-sulfo-isophthalate residues may be added to provide dyeability of the polyester filaments with cationic dyestuffs, as disclosed by Griffing and Remington U. S. Patent No. 3,018,272, Hagewood etal in U. S. Patent No.

15 4,929,698, Duncan and Scrivener U. S. Patent No. 4,041,689 (Ex. VI), and Piazza and Reese U. S. Patent. No. 3,772,872 (Ex. VII). To adjust the dyeability or other properties of the spin-oriented filaments and the drawn filaments therefrom, some diethylene glycol (DEG)

20 may be added to the polyester polymer as disclosed by Bosley and Duncan U. S. Patent No. 4,025,592 and in combination with chain-branching agents as described in Goodley and Taylor U. S. Patent No. 4,945,151.

According to the present invention there is

25 provided a process for preparing spin-oriented polyester filaments having a fineness, for example, in the range of about 1 to about 0.2 denier per filament (dpf), preferably in the range about 0.8 to about 0.2 denier per filament (dpf);

30 (a) by melting and heating said polyester polymer, as described herein before, to a temperature (T_P) in the range of about 25°C to about 55°C, preferably in the range of about 30°C to about 50°C, above the apparent melting temperature $(T_M)_a$, wherein,

$(T_M)_a$ is greater than the zero-shear melting
temperature (T_M^0) as a result of the shearing action of
the polymer during extrusion and is defined, herein,
by:

5              $$(T_M)_a = [T_M^0 + 2 \times 10^{-4} (L/D_{RND}) G_a],$$

where L is the length of the capillary and D_{RND} is the
capillary diameter for a round capillary, or for a non-
round capillary, wherein, for a non-round capillary,
D_{RND} (cm) is the calculated equivalent diameter of a
10   round capillary of equal cross-section area A_c (cm^2);
and G_a (sec^{-1}) is the apparent capillary shear rate
defined, herein after;

          (b) filtering the resulting polymer melt
through inert medium, such as described by Phillips in
15   U. S. Patent No. 3,965,010, in a pack cavity (similar
to that illustrated in FIG. 2-31 of Jamieson U. S.
Patent No. 3,249,669), sufficiently rapidly that the
residence time (t_r) is less than about 4 minutes,
wherein, t_r is defined by ratio (V_F/Q) of the free-
20   volume (V_F, cm^3) of the filter cavity (filled with the
inert filtration medium) and the polymer melt volume
flow rate $(Q, cm^3/min)$ through the filter cavity. The
polymer melt volume flow rate (Q) through the filter
cavity is defined by the product of the capillary mass
25   flow rate (w, g/min) and the number of capillaries ($\#_c$)
per cavity divided by the melt density (herein taken to
be about 1.2195 g/cm^3); that is, $Q = \#_c w/1.2195$. The
free-volume (V_F, cm^3) of the filter cavity (filled with
the inert filtration medium) is experimentally
30   determined by standard liquid displacement techniques
using a low surface tension liquid, such as ethanol.
By replacing the capillary mass flow rate (w), by its
equivalent $w = [(dpf \cdot V)/9]$, (where V is the withdrawal
spin speed expressed as km/min), in above expression

for the melt residence time t_r, it is found that the
residence time t_r decreases with increasing filament
denier, withdrawal speed (V) and number of filaments
($\#_c$) per filter cavity, and decreases with a reduction
5   in the filter cavity free-volume (V_F). The cavity
free-volume (V_F) may be decreased by altering the pack
cavity dimensions and by utilizing inert material which
provides sufficient filtration capabilities with less
free-volume. The number of filaments (i.e,
10   capillaries) per filter cavity ($\#_c$) may be increased
for a given yarn count by extruding more than one
multifilament bundle from a single filter cavity, that
is, spinning a larger number of filaments and then
splitting (herein, called multi-ending) the filament
15   bundle into smaller filament bundles of desired yarn
denier, preferably by using metered finish tip
separator guides positioned between about 50 cm to
about $(50+90dpf^{\frac{1}{2}})$cm;

         (c) the filtered polymer melt is extruded
20   through a spinneret capillary at a mass flow rate (w)
in the range of about 0.07 to about 0.7 grams per
minute (g/min) and the capillary is selected to have a
cross-sectional area, $A_c = (\pi/4)D_{RND}^2$, in the range of
about 125×10^{-6} cm^2 (19.4 mils^2) to about 1250×10^{-6} cm^2
25   (194 mils^2), preferably in the range of about 125×10^{-6}
cm^2 (19.4 mils^2) to about 750×10^{-6} cm^2 (116 mils^2), and
a length (L) and diameter (D_{RND}) such that the L/D_{RND}-
ratio is in the range of about 1.25 to about 6,
preferably in the range of about 1.25 to about 4;
30   wherein,

$$G_a \ (sec^{-1}) = [(32/60\pi)(w/\rho)/D_{RND}^3],$$

and w is the capillary mass flow rate (g/min), ρ is the
polyester melt density (taken as 1.2195 g/cm^3), and
D_{RND} is the capillary diameter (defined herein before)

in centimeters (cm);

(d) protecting the freshly extruded polymer melt from direct cooling, as it emerges from the spinneret capillary over a distance L_{DQ} of at least
5   about 2 cm and less than about $(12dpf^{1/2})$cm, where dpf is the denier per filament of the spin-oriented polyester fine filament;

(e) carefully cooling the extruded melt to below the polymer glass-transition temperature (T_g),
10   wherein, said cooling may be achieved by use of laminar cross-flow quench fitted with a delay tube (as described in Makansi U. S. Patent No. 4,529,368), and preferably by radially directed air (as described in Dauchert U. S. Patent No. 3,067,458), wherein the
15   temperature (T_a) of the quench air is less than about T_g and the velocity (V_a) of the quench air is in the range of about 10 to about 30 m/min;

f) while attenuating the cooled melt to an apparent spinline strain (ε_a) in the range of about 5.7
20   to about 7.6, preferably in the range of about 6 to about 7.3, wherein, the apparent spinline strain ε_a is defined as the natural logarithm (ln) of the spinline extension ratio (E_R), and E_R is the ratio of the withdrawal speed (V) and the capillary extrusion speed
25   (V_o); that is, for D_{RND} in centimeters, ε_a is given by:

$$\ln(E_R) = \ln(V/V_o) = \ln[(2.25 \times 10^5 \pi \rho)(D_{RND}^2/dpf)];$$

g) providing during attenuation the development of an apparent internal spinline stress (σ_a) in the range of about 0.045 to about 0.195 g/d,
30   preferably in the range of about 0.045 to about 0.105 g/d for preparing spin-oriented filaments, especially suitable for draw feed yarns (DFY), characterized with tenacity-at-7%-elongation (T_7) values in the range of

about 0.5 to about 1 g/d, and preferably an apparent internal spinline stress (σ_a) in the range of about 0.105 to about 0.195 g/d for preparing spin-oriented filaments especially suitable for direct-use yarns

5 (DUY), characterized by tenacity-at-7%-elongation (T_7) in the range of about 1 to about 1.75 g/d; wherein, the apparent internal spinline stress (σ_a) is defined herein by the product of the apparent viscosity of the attenuating melt (η_m) and the spinline velocity

10 gradient (dV/dx) at the point that attenuation is essentially complete (herein referred to as the 'neck-point'; and the apparent internal spinline stress (σ_a) is found to increase with increasing polymer LRV and withdrawal speed (V) and to decrease with increasing

15 filament dpf, number of filaments ($\#_c$) for a given spinneret surface area (A_0 cm^2) and polymer temperature (T_p); and herein is expressed by an empirical analytical relationship of the form:

$$(\sigma_a) = k(LRV/LRV_{20.8})(T_R/T_P)^6(V^2/dpf)(A_0/\#_c)^{0.7},$$

20 wherein k has an approximate value of $10^{-2}(\rho_m/SOC)$, where ρ_m is the density of the spin-oriented filaments (e.g., in the range of about 1.345 to about 1.385 g/cm^3, that is about 1.36 g/cm^3) and SOC is the "stress-optical coefficient" for the polyester polymer

25 (e.g., about 0.7 in reciprocal g/d for 2GT homopolymer); T_R is the polymer reference temperature defined by (T_M^O + 40°C) where T_M^O is the zero-shear (DSC) polymer melting point; T_P is the polymer melt spin temperature, °C; V is the withdrawal speed

30 expressed in km/min; $\#_c$ is the number of filaments (i.e., capillaries) for a given extrusion surface, A_0, expressed as $\#_c/cm^2$; LRV is the measured polymer (lab) viscosity and $LRV_{20.8}$ is the corresponding reference LRV-value (where LRV is defined herein after) of the

35 polyester polymer having the same zero-shear

"Newtonian" melt viscosity (η_0) at 295°C as that of 2GT homopolymer having an LRV-value of 20.8 (e.g., cationic-dyeable polyester of 15 LRV is found to have a melt viscosity as indicated by capillary pressure drop

5   in the range of 2GT homopolymer of about 20 LRV and thereby a preferred reference LRV for such modified polymers is about 15.5 and is determined experimentally from standard capillary pressure drop measurements);

(h) converging the cooled and fully

10 attenuated filaments into a multifilament bundle by use of a low friction surface, (that is, in a manner that does not abrade nor snub the filaments), such as by a finish roll, and preferably by a metered finish tip applicator (as described in Agers U. S. Patent No.

15 4,926,661), at a distance (L_C) from the face of the spinneret in the range of about 50 cm to about 140 cm, preferably in the range of about 50 cm to about $(50+90dpf^{\frac{1}{2}})$cm, wherein the finish is usually an aqueous emulsion of about 5% to about 20% by weight solids and

20 finish-on-yarn is about 0.4% to about 2% by weight solids, depending on the end-use processing requirements;

(i) interlacing the filament bundle using an air jet, essentially as described by Bunting and Nelson

25 in U. S. Patent No. 2,985,995 and by Gray in U. S. Patent No. 3,563,021, wherein, the degree of interfilament entanglement (herein referred to as rapid pin count RPC as measured according to Hitt in U. S. Patent No. 3,290,932), is selected based on yarn

30 packaging and end-use requirements;

(j) winding up the multifilament bundle at a withdrawal speed (V), herein defined as the surface speed of the first driven roll, in the range of about 2 to about 6 km/min, preferably in the range of about 2

to about 5 km/min, and especially in the range of about
2.5 to about 4.5 km/min; wherein the retractive forces
from aerodynamic drag are reduced by relaxing the
spinline between the first driven roll and the windup
5   roll by overfeeding in the range of about 0.5 to about
5%, without the application of heat (except for use of
heated interlace jet fluid (such as heated air or
water-saturated air) for preventing finish deposits
forming on the interlace jet surfaces as described by
10 Harris in U. S. Patent No. 4,932,109.

        The polyester fine filaments of this
invention are manufactured by a simplified direct spin-
orientation (SDSO) process which does not incorporate
drawing or heat treatment, and therein provides a
15 preferred balance of shrinkage and dyeability behavior
making the polyester fine filaments of the invention
especially suitable for replacement of natural
continuous filaments, such as silk. By careful
selection of SDSO process parameters fine filaments
20 with excellent mechanical quality and uniformity are
made; such that the fine filaments, having shrinkages
less than about 12%, may be used in multifilament
direct-use yarns (DUY) and processed without forming
broken filaments in high speed weaving and knitting;
25 and filaments, having shrinkages preferably greater
than about 12%, may be used in multifilament draw-feed
yarns (DFY) in high speed textile draw processes, such
as friction-twist texturing, air-jet texturing,
stuffer-box crimping and warp-drawing, without forming
30 broken filaments.

        The fine filaments of this invention are
characterized by having excellent mechanical quality
permitting yarns made from these filaments to be used
in high speed textile processes, such as draw false-
35 twist and air-jet texturing, warp drawing, draw gear

and stuffer-box crimping, and air and water jet weaving
and warp knitting, without broken filaments; and the
filaments of this invention are further characterized
by having excellent denier uniformity (as defined

5   herein by along-end denier spread, DS) permitting use
in critically dyed fabrics. The filaments of this
invention may be used as filaments in draw feed yarns
(and tows), preferably filaments having boil-off
shrinkage (S) and dry heat shrinkage (DHS) greater than

10   about 12% are especially suitable for draw feed yarns;
and filaments of this invention, having shrinkages less
than about 12%, are especially suitable flat untextured
multifilament yarns, and as yarns for such texturing
processes as air-jet texturing, gear crimping, and

15   stuffer-box crimping, wherein, no draw need be taken,
and the flat and textured filaments of this invention
may be cut into staple fibers and flock; but the
filaments with shrinkages less than about 12% may be
uniformly cold drawn as described by Knox and Noe in U.

20   S. Patent No. 5,066,447.

In contrast to the polyester fine filaments
prepared according the invention, fine filaments made
by such spinning technologies, which incorporate, for
example, aerodynamic or mechanical draw and/or heat

25   treatment steps for the reduction in filament denier
and/or for the increase in molecular orientation and/or
crystallinity, which are generally characterized by: 1)
high shrinkage tension (ST_{max}) greater than about 0.2
g/d; 2) peak shrinkage tension occurring at

30   temperatures, $T(ST_{max})$, greater than about 100°C (i.e.,
greater than atmospheric dyeing temperatures); 3) dry
heat shrinkage (DHS) which increases with treatment
temperature over the normal textile dyeing and
finishing temperature range of about 100°C to about

35   180°C (that is, having a $d(DHS)/dT > 0$ for T = 100°C to

180°C) and a differential shrinkage, (ΔS = DHS-S),
greater than about +2%, where S is the boil-off
shrinkage and DHS is the dry heat shrinkage, and
thereby requiring high temperature treatments of the
5   polyester fine filaments, or textile products made
therefrom, prior to, or after dyeing, to impart
sufficient thermal dimensional stability to the textile
fabrics made from these fine filaments; and 4) inferior
dyeability, requiring dyeing under pressure at high
10   temperatures with chemical dye assists, called
carriers, to achieve deep shades and uniform dyed
fabrics.

In particular, according to the present
invention, there are provided:

15   1. Spin-oriented polyester fine filaments of
about 1 dpf or less, preferably less than about 0.8
dpf, especially less than about 0.6 dpf, and greater
than about 0.2 dpf; wherein said polyester is of
relative viscosity (LRV) in the range of about 13 to
20   about 23, with a zero-shear polymer melt temperature
(T_M^O) in the range of about 240°C to about 265°C, and
polymer glass transition temperature (T_g) in the range
of about 40°C to about 80°C; and said filaments are
further characterized by:

25   (a) a shrinkage differential, (ΔS = DHS-S),
less than about +2%, preferably less than about +1%,
and especially less than about 0%; wherein, S is boil-
off shrinkage and DHS is dry heat shrinkage measured at
180°C,

30   (b) a maximum shrinkage tension, (ST_{max}),
between about 0.05 and about 0.2 g/d, with the peak
temperature of maximum shrinkage tension, $T(ST_{max})$,
between about (T_g+5°C) and about (T_g+30°C); i.e.,

between about 75°C and about 100°C for poly(ethylene terephthalate) with a polymer T_g of about 70°C;

(c) a tenacity-at-7%-elongation (T_7) in the range of about 0.5 to about 1.75 g/d and a $[(T_B)_n/T_7])$-ratio at least about $(5/T_7)$; preferably at least about $(6/T_7)$, wherein, $(T_B)_n$ is the tenacity-at-break normalized to a reference LRV of 20.8 and percent delusterant (such as TiO_2) of 0%, defined by: $(T_B)_n = (T_B)[20.8/LRV)^{0.75}](1-X)^{-4}$; where tenacity-at-break, $(T_B) = T(1+E_B/100)$; E_B, the percent elongation-at-break, is between about 40% and about 160%; X is the fractional weight percent of delusterant; and T is the tenacity defined as breaking load (grams) divided by original undrawn denier;

(e) an average along-end denier spread (DS) of less than about 4%, preferably less than about 3%, and especially less than 2%.

2. Spin-oriented fine filaments, especially suitable as use as draw feed yarns (DFY), such as for high speed draw false-twist and air jet texturing, draw warping, draw crimping and stuffer-box texturing, wherein, said filaments are further characterized by:

(a) boil-off shrinkage (S) and dry heat shrinkage (DHS) greater than about 12% and less than about the maximum shrinkage potential, $(S_M = [(550-E_B)/6.5])$%, and for elongation-at-break (E_B) in the range of about 80% to about 160%;

(b) tenacity-at-7% elongation (T_7) in the range of about 0.5 to about 1 g/d.

3. Spin-oriented fine filaments, especially suitable for use as direct-use yarns (DUY), are further characterized by:

(a) boil-off shrinkage (S) and dry heat
shrinkage (DHS) between in the range of about 2% to
about 12%, preferably in the range of about 6% to about
12% for woven and preferably in the range of about 2%
to about 6% for knits, such that the filament denier
after boil-off, dpf(ABO) = dpf(BBO)x[(100/(100-S)], is
in the range of about 1 to about 0.2 dpf, preferably in
the range of about 0.8 to about 0.2 dpf, and especially
in the range of about 0.6 to about 0.2 dpf;

(b) tenacity-at-7%-elongation (T_7) in the
range of about 1 to about 1.75 g/d with an elongation-
at-break (E_B) in the range of about 40% to about 90%;

(c) a post-yield modulus (M_{py}), as defined by
the secant tan β in FIG. 5 (that is, M_{py} =
$(1.2T_{20} -1.07T_7)/0.13)$, in the range of about 2 to
about 12 g/d.

4. Spin-oriented fine filaments, capable of
being cold drawn without heat setting to provide
textile filaments, as further characterized by:

(i) a boil-off shrinkage (S) and dry heat
shrinkage (DHS) less than about 12%;

(ii) an onset of cold crystallization, T_{cc}
(DCS), of less than about 105°C, as measured by
differential scanning calorimetry (DSC) at a heating
rate of 20°C per minute;

(iii) an instantaneous tensile modulus, M_i
(= d(stress)/d(elongation)]x100, greater than about 0;
wherein [d(stress)/d(elongation)] is the tangent to a
plot of stress (grams per drawn denier) versus percent
elongation; and wherein draw stress is the draw force
(grams) divided by the drawn denier, where the drawn
denier is defined the ratio of the undrawn denier and

the residual draw-ratio, $(RDR = 1+E_B,\%/100)$;

The shrinkage (S) of said drawn filaments may be reduced, if desired, without significant loss in dyeability provided that the post heat set temperature

5   (T_{set}) is less than about the temperature at which the shrinkage tension undergoes no significant further reduction with increasing temperature; that is, it is preferred to maintain T_{set} less than about the temperature at which the onset of rapid (re)-

10   crystallization begins. The maximum value for T_{set}, is herein, defined as the temperature, at which the slope, $[d(ST)/dT]$, of a shrinkage tension versus temperature spectrum abruptly decreases in value (becoming less negative) - see FIG. 11.

15   5. Preferred drawn yarns made by drawing the said spin-oriented filaments of this invention and said drawn yarns are characterized by:

(a) denier per filament after boil-off shrinkage, dpf(ABO), in the range of about 1 to about

20   0.2 dpf, and preferably in the range of about 0.8 to about 0.2 dpf;

(b) boil-off shrinkages (S) and dry heat shrinkages (DHS) in the range of about 2% to about 12%, preferably in the range of about 2% to about 6% for

25   knits, and in the range of about 6% to about 10% for wovens;

(c) tenacity-at-7%-elongation (T_7) at least about 1 g/d, such that the $[(T_B)_n/T_7]$-ratio is at least about $(5/T_7)$; preferably at least about $(6/T_7)$,

30   wherein, $(T_B)_n$ is the tenacity-at-break normalized to a reference LRV of 20.8 and percent delusterant (such as TiO_2) of 0%, and having an E_B in the range of about 15% to about 55%;

(e) post-yield modulus (M_{py}) in the range of
about 5 to about 25 g/d;

(f) relative disperse dye rate (RDDR),
normalized to 1 dpf, of at least about 0.1, and
5   preferably at least about 0.15;

(g) a dynamic loss modulus peak temperature,
$T(E''max)$ less than about 115°C; and preferably less
than about 110°C;

(h) an average along-end denier spread (DS)
10   of less than about 4%, preferably less than about 3%,
especially less than about 2%.

6. Bulky fine filament yarns (or tows) are
provided by passing the fine filament yarns of this
invention through a bulking process, such as air-jet
15   texturing, false-twist texturing, stuffer-box and gear
crimping; wherein, said bulky filaments are
characterized by having individual filament deniers
(after shrinkage) less than about 1, preferably less
than about 0.8, with boil-off shrinkage (S) and dry
20   heat shrinkage (DHS) less than about 12% and
characterized by a $T(E''_{max})$ of less than about 115°C,
preferably less than about 110°C, and a RDDR of at
least about 0.1, and preferably at least about 0.15.

Especially preferred filaments for use in
25   direct-use yarns (or tows) are also characterized by:

(a) an average crystal size (CS), as measured
from the 010 plane by wide-angle x-ray scattering
(WAXS), between about 50 and about 90 angstroms (Å)
with a fractional volume crystallinity, X_v =
30   (ρ_m -1.335)/0.12, between about 0.2 and about 0.5 for
density values (ρ_m) between about 1.355 and about 1.395
grams/cm^3, corrected for percent delusterant;

(b) an fractional average orientation function, $f = \Delta_n/\Delta_n^\circ$ (where Δ_n° is the average intrinsic birefringence (defined herein with a value of 0.22), between about 0.25 and about 0.5, with a fractional amorphous orientation function, $f_a = (f - X_v f_c)/(1 - X_v)$), less than about 0.4, preferably less than about 0.3, wherein (Δ_n) is the average birefringence and f_c is the fractional crystalline orientation function, $f_c = (180 - COA)/180$, where COA is the crystalline orientation angle as measured by WAXS;

(c) an amorphous free-volume ($V_{f,am}$) of at least about 0.5×10^6 cubic angstroms (Å^3), preferably at least about 1×10^6 Å^3, where $V_{f,am}$ is defined herein by $(CS)^3[(1-X_v)/X_v)][(1-f_a)/f_a]$, providing a dynamic loss modulus peak temperature, $T(E''_{max})$, less than about 115°C, and preferably less than about 110°C;

(d) an atmospheric relative disperse dye rate (RDDR), normalized to 1 dpf, of at least about 0.1, and preferably at least about 0.15.

The yarn characteristics are measured as in U. S. Patent Nos. 4,134,882, 4,156,071, and 5,066,447; except the relative disperse dye rate (RDDR) is normalized to 1 dpf, dry heat shrinkage (DHS) is measured at 180C, and the lab relative viscosity (LRV) is defined according to Broaddus in U. S. Patent No. 4,712,998 and is equal to about (HRV - 1.2), where HRV is given in U. S. Patents Nos. 4,134,882 and 4,156,071. The value of $LRV_{20.8}$ is taken as the reference LRV of the polyester polymer of equal zero-shear "Newtonian" melt viscosity η_o to that of 20.8 LRV 2GT homopolymer (e.g., providing for the same capillary pressure drop at the same mass flow rate and temperature). In Tables I through VIII, alphanumerics which are "raised to the power" of a number is expressed using the symbol "^"

(such as $10^2 = 10^2$); very small or very large numbers
(such as 0.00254 cm and 254000 cm/min, for example) are
expressed, for convenience as 0.254 and 254 where the
units are given as "cm x 10^2" and "cm/sec x 10^-3,
respectively; dashes (---) in the place of a number
denotes that the value was not measured; "NA" in the
place of a number denotes that the measured value is
not applicable; and dashed arrows (----->) are used to
denote values of a given parameter for a given item is
the same as that of the preceeding item. Spin speed
(V) was measured in yards/minute and have been
converted in the text to km/minute, rounded to the
second decimal place (e.g., 4500 ypm = 4.115 km/min =>
4.12).

        The preferred embodiments of this invention
are illustrated by the following examples:

        Poly(ethylene terephthalate) having a polymer
LRV in the range of about 13 to about 23 (which
corresponds to an $[\eta]$ in the range of about 0.5 to
about 0.7), preferably in the range of about 13 to
about 18 for ionically modified polyesters, and in the
range of about 18 to about 23 for nonionically modified
polyesters, a zero-shear melting point (T_M^o) in the
range of about 240°C to about 265°C, and a glass-
transition temperature (T_g) in the range of about 40°C
to about 80°C, and containing minor amounts of
delusterants and surface friction modifiers (e.g., TiO_2
and SiO_2), is melted at a polymer temperature T_P (°C)
and filtered through inert medium for a residence
(hold-up) time (t_r, min) and then extruded through
spinneret capillaries of diameter (D_{RND}) with length
(L) at a capillary mass flow rate w [$= (dpf \cdot V)/9$],
g/min] providing an apparent capillary shear rate (G_a,
sec$^{-1} = [(32/60\pi)(w/\rho)/D_{RND}^3)]$, where capillary
dimensions are expressed in units of centimeters and

the withdrawal spin speed (V) in units of km/min.

The filaments of most of the examples herein were spun from spinnerets having a filament density per extrusion surface area in the range of typically about

5   2.5 to about 13, while it was possible to spin and quench filament bundles with a extrusion filament density as high as about 25 provided capillary hole pattern (filament array) was optimized for the type of quench (i.e., radial vs. cross-flow) and length/profile

10 of the initial delay quench "shroud" and air velocity profile (see Example I); wherein the extrusion filament density is defined by the ratio of the number of filaments ($\#_C$) divided by the extrusion surface area (A_O), (i.e., $\#_C/A_O$, cm^{-2}), into a "shroud" which protects

15 the freshly extruded filaments from direct quench air for a distance at least about 2 cm and not greater than about ($12dpf^{\frac{1}{2}}$, cm); and then carefully cooled to a temperature less than about polymer T_g, preferably by radially directed air having a temperature T_a (herein

20 about 22°C) less than about the polymer T_g (herein T_a was about 70°C for 2GT homopolymer) and of linear velocity V_a (m/min) in the range of about 10 to about 30 m/min. Suitable spinning apparatus used are essentially as that described in U. S. Patent Nos.

25 4,134,882, 4,156,071, and 4,529,368.

The along-end denier spread (DS) and draw tension variation (DTV) were minimized by balancing the values for the delay quench length (L_{DQ}), the quench air temperature (T_a), the quench air flow rate (V_a),

30 and the convergence length (L_c), while selecting T_P for spinning continuity. Increasing the polymer spin temperature (T_P) (but less than about [$(T_M)_a$ + 55°C] usually increases spinning continuity and mechanical quality (i.e., T_B, g/d), but usually decreases along-

35 end uniformity and increases shrinkage. To minimize

loss of along-end uniformity while spinning at elevated
temperatures (T_P), as required for mechanical quality,
heat can be imparted to the extruded filaments through
use of high shear rate (G_a) capillaries (that is, small
5   diameter capillaries). However, the spinning
operability unexpectedly deteriorated when high shear
capillaries are used with high L/D_{RND} ratios, such as
use of a 9x50 mil capillary (see Example III). It is
conjectured that at these low capillary mass flow rates
10   and high shear conditions, incipient shear-induced
molecular ordering (e.g., lower chain entropy and
possible incipient "nucleation") of the polymer melt
occurs, especially for polymer melt filtered prior to
extrusion for residence times (t_r) greater than about 4
15   minutes, wherein this molecular ordering (possible
incipient nucleation) is believed to increase the
apparent polymer melting point from the zero-shear
value (T_M^o) to an apparent value $(T_M)_a$. This has the
effect of reducing the spin temperature differential,
20   $T_P-(T_M)_a$. To maintain a sufficiently large enough spin
temperature differential, it is found that the bulk
polymer temperature T_P needs to be further increased as
given by the amount defined by the expression:
$2 \times 10^{-4} (L/D_{RND}) G_a$, °C, for the selected values of L,
25   D_{RND}, and G_a.

To obtain a balance of spinning continuity,
mechanical quality and along-end uniformity, the
apparent internal spinline stress (σ_a) at the "neck-
point" is controlled in the range of about 0.045 to
30   about 0.195 g/d while controlling the melt extension
strain ε_a in the range of about 5.7 to about 7.6. The
attenuated and cooled filaments are converged into a
multifilament bundle and withdrawn at a spinning speed
(V, km/min) as defined by the surface speed of the
35   first driven roll. The external spinline tension

arising from frictional surfaces (and air drag) is
removed prior to packaging by slightly over feeding the
spinline between the first driven roll and the windup,
usually between about 0.5% and 5%. Finish is applied
5   at the point of convergence and interlace is provided,
preferably after the first driven roll. The values for
finish-on-yarn (weight, %) and degree of filament
entanglement (RPC) are selected to meet end-use
processing needs.

10   Polyester fine filaments of the invention are
of good mechanical quality and uniformity having a
linear density less than about of that of natural worm
silk, but greater than that of spider silk, that is
between about 1 and about 0.2 denier per filament, and
15   having the capability of being uniformly dyed without
use of high temperatures and chemical dye assists; that
is, more akin to that of natural silks.

            Advantageously, if desired, the fine denier
filament yarns may be treated with caustic in spin
20   finish (according to the invention as taught by
Grindstaff and Reese in the copending allowed Patent
Application Serial No. 07/420,459, filed October 12,
1989) to enhance their hydrophilicity and improved
moisture-transport and comfort. Incorporating
25   filaments of different deniers and/or cross-sections
may be used to reduce filament-to-filament packing and
thereby improve tactile aesthetics and comfort. Unique
dyeability effects may be obtained by co-mingling
filaments of differing polymer modifications, such as
30   homopolymer dyeable with disperse dyes and ionic
copolymers dyeable with cationic dyes.

            Fine filaments of lower shrinkage may be
obtained, if desired, by incorporating chain branching
agents, on the order of about 0.1 mole percent, as

described in part in Knox U. S. Patent No. 4,156,071,
MacLean U. S. Patent No. 4,092,229, and Reese in U. S.
Patents Nos. 4,883,032, 4,996,740, and 5,034,174;
and/or increasing polymer viscosity by about +0.5 to
5   about +1.0 LRV units.

          The fine filament yarns of this invention are
suitable for warp drawing, air jet texturing, false-
twist texturing, gear crimping, and stuffer-box
crimping, for example; and the low shrinkage filament
10   yarns may be used as direct-use flat textile yarns and
a feed yarns for air-jet texturing and stuffer-box
crimping wherein no draw is need be taken. The
filaments (and tows made therefrom) may also be crimped
(if desired) and cut into staple and flock. The
15   fabrics made from these improved yarns may be surface
treated by conventional sanding and brushing to give
suede-like tactility. The filament surface frictional
characteristics may be changed by selection of cross-
section, delusterant, and through such treatments as
20   alkali-etching. The improved combination of filament
strength and uniformity makes these filaments,
especially suited for end-use processes that require
fine filament yarns without broken filaments (and
filament breakage) and uniform dyeing with critical
25   dyes.

          The fine denier filament polyester yarns of
the invention are especially suitable for making of
high-end density moisture-barrier fabrics, such as
rainwear and medical garments. The surface of the knit
30   and woven fabrics can be napped (brushed or sanded).
To reduce the denier even further, the filaments may be
treated (preferably in fabric form) with conventional
alkali procedures. The fine filament yarns, especially
those capable of being cationic dyeable, may also be
35   used as covering yarns of elastomeric treatments yarns

(and strips), preferably by air entanglement as
described by Strachan in U. S. Patent No. 3,940,917.
The fine filaments of the invention may be co-mingled
on-line in spinning or off-line with higher denier

5   polyester (or nylon) filaments to provide for cross-
dyed effects and/or mixed shrinkage post-bulkable
potential, where the bulk may be developed off-line,
such as over feeding in presence of heat while
beaming/slashing or in fabric form, such as in the dye

10   bath. The degree of interlace and type/amount of
finish applied during spinning is selected based on the
textile processing needs and final desired yarn/fabric
aesthetics.

     The process of this invention and the product

15   made therefrom is further illustrated by the following
examples:

EXAMPLE I

     Yarns of 100 and 300 filaments of nominal 0.5
dpf were spun from poly(ethylene terephthalate) of 19

20   LRV (corresponding to about 0.60 [η]) and containing
0.3 weight percent of TiO_2. The 300-filament yarns
were spun using spinnerets of varying construction;
e.g. so to provide: (i) 2 or more capillaries from a
single counterbore without inter-filament fusion by

25   controlling the capillary-to capillary distance greater
than about 40 mils (1 mm); (ii) 300 "equally-spaced"
single capillaries; and (iii) 300 capillaries arranged
in concentric rings occupying about "initially" 50% of
the "outer" half of the available extrusion surface

30   area (A_o) so to increase the effective extrusion
filament density (EFD) from about 12.5 to about 25;
however, immediately after extrusion the polymer melt
streams of spinneret (iii) converge to form a conical
bundle similar to that of spinnerets (i) and (ii); and

therebyhaving an effective extrusion filament density
(EFD) on the order of that for the spinneret
constructions (i) and (ii); i.e. less than 25 and
larger than, 12.5, where the effective extrusion
5   filament density (EFD) for such non-equally distributed
filament configurations is experimentally determined
following the graphical procedure in Figure 14.
Experimentally, filaments equally spaced over the
entire extrusion area and filaments spaced on the
10   perimeter in concentric rings are found to have about
the same effective filament extrusion density since the
filaments bundles, immediately after extrusion, assume
similar configurations. The data in Table I for the
300-filament yarns were spun with capillaries arranged
15   in concentric rings occupying initially about 50% of
the available extrusion surface area. The freshly
extruded filaments were cooled to room temperature by
using a radial quench apparatus, essentially as
described in U. S. Patent No. 4,156,071, except for
20   having a protective "shroud" of length (L_{DQ}) of about 1
inch (2.54 cm) for yarns spun at 3500 ypm (3.2 km/min)
and about 2.25 inches (5.72 cm) for yarns spun at 4500
ypm (4.12 km/min). The filament yarns spun at 3500 ypm
(3.2 km/min) had a high boil-off shrinkage (S), making
25   these yarns especially suitable, for example, as draw
feed yarns (DFY) in draw warping, draw air-jet
texturing, draw false-twist texturing, and draw
crimping. Increasing the spin speed to 4500 ypm (4.115
km/min), decreased boil-off shrinkage (S) to values
30   less than 12% with a differential shrinkage (ΔS = DHS-
S) less +2%, a maximum shrinkage tension (ST_{max}) less
than 0.175 g/d at a peak temperatures $T(ST_{max})$ less
than 100°C, and a yield tenacity (herein approximated
by the tenacity-at-7% elongation, T_7) greater than 1
35   g/d, making these filaments fully suitable for direct-
use applications without requiring additional drawing

or heat treatment, such as use as filaments in flat, air-jet textured and stuffer-box crimped textile filament yarns.

It was observed that the filaments spun from
5   spinneret capillaries with a cross-sectional area (A_C)
of 176.8 mils^2 (0.1140 mm^2, 1.14×10^{-3} cm^2) had a lower
tenacity-at-break (T_B) than the filaments spun from
spinneret capillaries with an A_C of 28.3 mils^2 (.0182
mm^2, 1.82×10^{-4} cm^2). The lower tenacity of the yarns
10   of this Example I, is also ,in part, due to the lower
polymer LRV (19 vs. 20.8). The normalized values for
T_B (denoted herein by $(T_B)_n$) are defined by the product
the measured tenacity-at-break (T_B) and the factor
$(20.8/LRV)^{0.75}(1-X)^{-4}$ which for these yarns is about
15   1.057; thereby, the normalized break tenacities $(T_B)_n$
are about 6% higher when compared to reference LRV and
% TiO$_2$ of 20.8 and 0%, respectively.

The fine filament yarns of this example were
capable of being dyed to deep shades at atmospheric
20   conditions (100°C) without use of dye carriers as given
by an Relative Disperse Dye rate (RDDR)-value
(normalized to a 1 dpf) of about 0.16 versus an RDDR-
value of 0.055 for a conventional fully drawn yarn.

To provide yarns of fewer filaments (and
25   lower denier), it is possible to split, for example,
the 300-filament yarn bundle into 2,3 or 4 individual
bundles of 150, 100, and 75-filament yarn bundles,
respectively, preferably by use of metered finish tip
separating guides at the exit of the radial quench
30   chamber. Multi-ending permits a higher mass flow rate
(w) through the filter pack cavity and thereby reducing
the residence time (t_r) in the pack cavity per
threadline.

EXAMPLE II

Fine filaments were spun from poly(ethylene terephthalate) of nominal 20.8 LRV (about 0.65 [η]) and containing 0.1 weight percent TiO_2 at a withdrawal
5   speed (V) of 4000 ypm (3.66 km/min) using a radial quench apparatus, essentially as described in Example I, except for having a delay "shroud" length (L_{DQ}) of about 2.25 inches (5.72 cm). Examples II-5 and II-6 had poor operability and no yarn was collected. The
10   low apparent shear rates (G_a) for the 0.5 dpf filaments spun at 4000 ypm (3.66 km/min) using 15x60 mil (0.38x1.52 mm, 0.038x0.152 cm) capillaries is believed to contribute to the poor operability and broken filaments. Even increasing temperatures T_P to about
15   299°C did not provide an acceptable process. Temperatures higher than 299°C-300°C were not tried because of the concern for poor along-end denier uniformity. Process and product details are summarized in Table I.

20   ## EXAMPLE III

In Example III, 68-and 136-(unplied and plied) filament yarns were spun, essentially according to Example I, except convergence was by a metered finish tip as described in U. S. Patent No. 4,926,661
25   for Examples III-1 through III-9 and III-11 through III-25. Example III-10 used a metering finish roll surface to converge the filaments as described in Examples I and II. Other process details are summarized in Tables I and II. The filaments of
30   Example III-1 through III-5 and III-12 through III-15 have T_7-values greater than about 1 g/d making them especially suitable for use as filaments in direct-use textile filament yarns and as feed yarns in air-jet textured, wherein no draw is taken; and, if desired,

can be drawn uniformly without heat (cold) in warp
drawing (and air-jet texturing) as described in Knox
and Noe U. S. Patent No. 5,066,447. The filaments of
III-6,7, and III-16 through III-25 with T_7-values less

5   than about 1 g/d are especially suitable as filaments
in draw feed yarns (DFY) , such as draw false-twist
texturing (FTT) and draw air-jet texturing (AJT) or as
draw feed yarns in warp drawing.

        In Examples III-1 through III-5, 50 denier

10   68-filament yarns were spun from a single pack cavity
and plied at the convergence guide to give a 100 denier
136-filament yarns of excellent mechanical quality.
Example III-4, for example, had a spinning continuity
of 0.39 breaks per 1000 lbs. (0.86 per 1000 kg) which

15   is equivalent to about 9.5 breaks per 10^9 meters. The
yarns of Example III-4 were wound with about 10 cm
interlace (as measured by the rapid pin count procedure
described in U. S. Patent No. 3,290,932) for air-jet
texturing on a Barmag FK6T-80 without drawing and wound

20   with about 5-7 RPC interlace for direct-use as a flat
textile yarn in wovens and warp knits. Example III-6
and 7 were drawn without broken filaments at 1.44X and
1.7X, respectively, to give drawn 35 denier 68-filament
yarns. Example III-6 is preferred versus III-7 since

25   the spinning productivity (spun denier x spin speed) of
III-6 is about 25% greater than Example III-7. Yarns
of Example III-6 were successfully cold warp drawn
using a 1.44X draw-ratio.

        It had been anticipated that increasing the

30   L/D_{RND}-ratio of the 9 mil (0.229 mm, 0.0229 cm)
capillary spinnerets from 2.22 to 5.56, as per the
teaching of Frankfort and Knox in U. S. Patent No.
4,134,882, would significantly improve mechanical
quality by providing for increased shear heating of the

35   extruding polymer melt; wherein the degree of capillary

shear heating was estimated by the expression in
Frankfort and Knox: $660(wL/D^4)^{0.685}$, °C, wherein D is
given mils, and w is given in lbs./hr.; however, broken
filaments were observed for Examples III-8 and III-11.

5   Acceptable quality was obtained for Example
III-12; wherein the residence time (t_r) during
filtration in the pack cavity was reduced by spinning
136-filaments versus 68-filaments. The yarn bundle
could be withdrawn as a single 136-filament bundle or
10   split to wind-up two 68-filament yarn bundles.
Residence times (t_r) less than about 4 minutes for high
L/D_{RND} capillary spinnerets are found to be necessary
to spin without having to use high "input" polymer
temperatures (T_p). See Example IX for a more detailed
15   discussion about the spinning with high shear capillary
spinnerets. In Examples III-12 through III-15, 136-
filament yarns were spun using 136-9x36 mil
(0.229x0.916 mm, 0.0229x0.0916 cm) capillaries per
spinneret, and thereby reducing the filtration
20   residence time (t_r) by 50%, to provide yarns with good
mechanical quality. The high filament count yarns are
especially suitable for draw air-jet texturing (AJT)
and for false-twist texturing (FTT), wherein, a
straight draw-texturing machine configuration is
25   preferred. Yarns from Examples III-19,22,24 and 25
were used for preparing warp drawn flat yarns of
nominal 0.5 dpf as described in Example XII.

          The structural properties of thɜ filaments of
Example III-10 are representative of spin-oriented
30   filaments of this invention having shrinkages less than
6%. Example III-10 had a density ([ρ-measured = ρ-
fiber - 0.0087(%TiO$_2$)] of 1.3667 g/cm^3 (corrected for
0.03% TiO$_2$), giving a calculated fractional volume
crystallinity [$X_v = (\rho_m-1.335)/0.12$] of 0.264, and a
35   weight percent crystallinity [$X_w = (1.455/\rho_c)X_v$] of

0.281; an average crystal size (CS) of 70 angstroms
(Å); an average crystal orientation angle (COA) of 12
degrees which corresponds to a crystal orientation
function $[f_c = (180-COA)/180]$ of 0.93; an average
5   birefringence (Δ_n) of 0.0744 giving an average
orientation function $[f = \Delta_n/0.22]$ of 0.34 and an
amorphous orientation function $[fa = (f-X_v f_c)/(1-X_v)]$
of 0.13 and an amorphous free-volume $[(V_{f,am}) = [(1-X_v)/X_v][(1-f_a)/f_a]CS^3]$ of about 6×10^6 cubic
10   angstroms ($Å^3$). The filaments of this example also had
a differential birefringence (Δ_{95-5}) of 0.0113, an N_{iso}
of 1.5882, a sonic velocity (SV) of 2.72 km/sec giving
a sonic modulus (M_{son}) of 83.6 g/d, a maximum shrinkage
tension (ST_{max}) of 0.143 g/d at a peak temperature,
15   $T(ST_{max})$, of 80°C, a boil-off shrinkage (S) of 4.6%,
giving a shrinkage modulus $[M_s = (ST_{max}/S)100]$ of 3.1
g/d, a dry heat shrinkage (DHS) of 5.0% to give a
differential shrinkage ($\Delta S = DHS-S$) of less than +1%,
an initial modulus of 71.6 g/d with a post-yield
20   modulus (M_{py}) of 5.35 g/d, and an uncorrected disperse
dye rate (DDR) of 0.144 and relative disperse dye rate
RDDR, normalized to 1 dpf, of about 0.104.

EXAMPLE IV

25   Poly(ethylene terephthalate) of nominal 21.2
LRV (about 0.66 $[\eta]$) of 0.035, 0.3 and 1 weight percent
TiO_2 were spun using a radial quench spinning
apparatus, essentially as described in Example I,
except the length (L_{DQ}) of the delay "shroud" was about
30   2-5/8 inches (6.7 cm), and the filament bundles were
converged by a metered finish tip at 43 inches (109 cm)
from the face of the spinneret. Other process details
are summarized in Tables III and IV. Increasing weight
percent TiO_2 is observed to decrease the tenacity-at-

break (T_B) of these fine filaments. The amount of TiO_2
is usually varied between about 0.035% for minimum
yarn-to-metal and yarn-to-yarn frictional needs and
less than about 1.5%, more typically less than about 1%
for desired mechanical quality and visual aesthetics.

EXAMPLE V

Poly(ethylene terephthalate) of nominal 21.1
LRV (about 0.655 [η]) and containing 0.3 weight percent
TiO_2 was spun using apparatus similar to Example IV.
Examples V-1 through V-4, IV-9 and IV-10 use 12x50 mil
(0.305x1.270 mm, 0.0305x0.127 cm) spinneret
capillaries. Examples V-5, 7, 8, and 11 through 13 use
9x36 mil (0.229x0.914 mm, 0.0229x0.0914 cm) spinneret
capillaries, and Example V-6 uses 6x18 mil (0.152x0.457
mm, 0.0152x0.0457 cm) spinneret capillaries to spin
100-filament 85 denier feed yarns for warp draw and
draw air-jet texturing (AJT). The length of delay
quench (L_{DQ}) was increased from 2-5/8 inches (6.7 cm)
to 4-5/8 inches (11.7 cm) in EX. V-8 and V-10.
Increasing the length of delay (L_{DQ}), increased along-
end non uniformity 4X and interfilament denier non
uniformity, as measured optically from yarn bundle
cross-sections, by 2X. When the delay length (L_{DQ}) is
less than about $(12 dpf^{\frac{1}{2}})$ cm, good uniformity may be
obtained.

Example V-7 was repeated for Examples V-11
through V-13 at 2400, 3000, and 3500 ypm (2.2, 3.05,
and 3.35 km/min); wherein, the capillary mass flow rate
(w) was varied to spin a draw feed yarn such that the
spun dpf would be drawn to a final denier of about 0.5
dpf [where, the drawn dpf = spun dpf/draw ratio = spun
dpf x (drawn yarn RDR/spun yarn RDR), where the

residual draw-ratio, RDR = (1+ E_B,%/100)]. Examples V-
11 through V-13 have tenacity-at-7%-elongation (T_7)
values less than about 1 g/d making them especially
suitable as draw feed yarns even though the shrinkages
5   of the undrawn yarns were less than 12%. The results
of the warp drawing are summarized in Example VII.

EXAMPLE VI

In Example VI, Example V-13 was repeated at
3300 ypm (3.02 km/min) for varying spun deniers, delay
10 quench lengths (L_{DQ}), spinning temperatures (T_P), and
convergence guide lengths (L_C). Example VI-2, with a
denier spread (DS) of 3.8% was successfully drawn 1.35X
to give a drawn 0.3 dpf 100-filament yarn with a 2.3%
denier spread, tenacity of 4.4 g/d, E_B of 32.5% and a
15 boil-off shrinkage(S) of 6.3%. In this example it was
observed that as total yarn bundle denier and
individual filament denier is reduced, the along-end
uniformity deteriorates unless the process is re-
balanced. Increasing polymer temperature to insure
20 good spinning continuity at these low mass flow rates
is required. The along-end denier spread (DS) was
improved from 12.1% (EX. VI-1) to less than 4% by
reducing the delay length (L_{DQ}) to about 2.9 cm and
decreasing the convergence length (L_C) from 109 cm to
25 81 cm. For yarns with dpf less than 0.5 it is
difficult to achieve the same DS-values as for those of
0.5 to about 1 dpf. Process and product details are
summarized in Tables III and IV.

EXAMPLE VII

30 Fine trilobal filaments were spun from
poly(ethylene terephthalate) of nominal 21 LRV (about
0.65 [η] containing 0.035 weight percent TiO_2 using
spinnerets with 9x36 mil (0.229x0.914 mm, 0.0229x0.0914

cm) and 12x50 mil (0.305x1.270 mm, 0.0305x0.127 cm)
metering capillaries and a Y-shaped exit orifices of
area (A_C) of about 197 mils^2 (1.27 mm^2, 0.0127 cm^2),
which corresponds to a D_{RND} of about 15.9 mils (0.40
5   mm, 0.04 cm) with an L/D_{RND} of about 1.5 (as
essentially as described in Examples 45-47 of U. S.
Patent No. 4,195,051). The 9x36 mil metering
capillaries provided better mechanical quality and
along-end denier uniformity than the 12x50 mil metering
10 capillaries. The 100-filament yarns could be drawn
without forming broken filaments to nominal 50 denier,
or about 0.5 dpf.

EXAMPLE VIII

Poly(ethylene terephthalate) polymer modified
15 with about 2 mole % of ethylene 5-sodium-sulfo
isophthate having a nominal LRV of about 15.3 was spun
using a laminar cross-flow quench apparatus with a 2.2
inches (5.6 cm) delay, essentially as described in U.
S. Patent No. 4,529,638, and converging the filament
20 bundle at about 43-inches (109 cm) with metered finish
tip guides. The lower LRV is usually preferred for
ionically modified polyesters because the ionic sites
act as cross linking agents and provide higher melt
viscosity. The 15 LRV used, herein, had a melt
25 viscosity about that of a 20 LRV homopolymer. If,
however, one wanted to spin low LRV homopolymer, then
typically it is advantageous to add viscosity builders,
such as tetra-ethyl silicate (as described in Mead and
Reese, U. S. Patent No. 3,335,211). It is generally
30 preferred to spin ionically modified polyesters with
LRV in the range of about 13 to about 18 and
nonionically modified polyesters with LRV in the range
of about 18 to about 23. Withdrawal speeds were
increased from 2400 ypm (2.2 km/min) to 3000 ypm (2.74
35 km/min). As expected the cationic copolymer yarns had

lower T_B-values based on their lower LRV. The lower
LRV is preferred for filaments yarns used in napped and
brushed fabrics and for tows to be cut into flock. The
as-spun yarns could be drawn without breaking filaments
5   to about 50 denier 100-filament yarns. The
cationically modified polyester had a RDDR value of
0.225 versus 0.125 for the 2GT homopolymer spun under
similar conditions.

EXAMPLE IX

10   Poly(ethylene terephthalate) of nominal 21.9
LRV (about 0.67 [η]) and containing 0.3 weight percent
TiO_2 was spun using apparatus similar to Example IV
with a air flow rate of about 30 m/min. Examples IX-1
through IX-3 use 12x50 mil (0.305x1.270 mm,
15   0.0305x0.127 cm) spinneret capillaries; Examples IX-4
through IX-8 use 9x36 mil (0.229x0.914 mm,
0.0229x0.0914 cm) spinneret capillaries; and Examples
IX-9 through IX-11 use 6x18 mil (0.152x0.457 mm,
0.0152x0.0457 cm) spinneret capillaries to spin nominal
20   50 denier 100-filament low-shrinkage yarns suitable as
direct-use textile yarns for warp knits and wovens and
as feed yarns for air-jet and stuffer-box texturing
wherein no draw is required.

It was expected that mechanical quality would
25   improve by increasing the capillary shear rate (G_a) as
taught by Frankfort and Knox in U. S. Patent No.
4,134,882. This improvement was observed for the 9x36
mil capillaries vs. the 12x50 mil capillaries; however,
unexpectedly, higher polymer temperatures were required
30   to spin with the 6x18 mil capillaries. From
calculations of polymer temperature increase due to the
higher shear rate (G_a), of the 6x18 mil capillaries, it
was expected the 6x18 mil capillaries would actually
require lower polymer temperatures (T_p) than that for

the 9x36 and 12x50 mil capillaries, as per the teaching
of Frankfort and Knox. However, it was necessary to
increase polymer temperature by about 5-6°C to provide
acceptable spinning continuity for the high shear 6x18
mil capillary spinnerets. It is speculated that at
these low mass flow rates (w), the higher shear of the
6x18 mil capillaries induces molecular ordering of the
polymer melt and may even induce nucleation with the
effect of increasing the apparent polymer melting point
$(T_M)_a$ as represented by the following empirical
expression for $(T_M)_a$ as a function of capillary shear
(Ga): that is, $(T_M)_a = T_M^O + 2 \times 10^{-4}[(L/D_{RND})(Ga), °C.$
The differential polymer spin temperature, defined
herein by:

$$[T_P-(T_M)_a] = [(T_P-T_M^O)-[2 \times 10^{-4} (L/D_{RND})Ga],$$

is effectively reduced as the product of the apparent
shear rate (G_a) and L/D_{RND}-ratio is increased; and
thereby requiring an increase in polymer temperature T_P
to maintain a minimum differential spin temperature at
least about 25°C and, preferably at least about 30°C
for spinning continuity. This is contrary to what is
expected from the teachings of Frankfort and Knox.
Process and product results are summarized in Tables IV
and V.

EXAMPLE X

Poly(ethylene terephthalate) of nominal 21.9
LRV (about 0.67 [η]) and containing 0.3 weight percent
TiO_2 was spun using apparatus similar to Example IV
with an air flow rate varied from about 11 to about 30
m/min. Examples X-1 through X-9 use 12x50 mil
(0.305x1.270 mm, 0.0305x0.127 cm) spinneret capillaries
and Examples X-10 through X-16 use 9x36 mil
(0.229x0.914 mm, 0.0229x0.0914 cm) spinneret

capillaries to spin nominal 70 denier 100-filament low-shrinkage yarns with T_7-values greater than about 1 g/d, making these especially suitable as direct-use textile yarns for warp knits and wovens and as feed

5   yarns for air-jet and stuffer-box texturing wherein no draw is required. It was observed that mechanical quality improved with higher polymer temperatures, and lower air flow rates. Changing the convergence guide distance L_c had little effect on mechanical properties,

10   as has been observed for higher dpf filaments (Bayer German Patent No. 2,814,104). Unfortunately the process changes which improve mechanical quality caused a deterioration in the along-end denier uniformity. Successful spinning of fine filaments with both good

15   mechanical quality and denier uniformity requires a balance between "hot" polymer for mechanical quality and "rapid" cooling of polymer for uniformity. This in contrary to the teachings of Frankfort and Knox which wherein the combination of "hot" polymer with slow

20   quenching by use of low quench rates, delay shrouds, and/or heated delay quench were used to provide for good quality filaments of deniers greater than 1. Balancing higher "input" polymer temperatures (T_P) with shear heating via smaller diameter capillary spinnerets

25   and rapid quenching via short delay lengths (L_{DQ}) permits, in general, a better balance of yarn properties. Shortening the convergence length (L_c) improved the uniformity and a reduction in winding tensions as a result of lower air drag. At the higher

30   spun deniers of Frankfort and Knox, no significant improvements are found for shortening the convergence length. Process and product results are summarized in Tables V and VI.

35

EXAMPLE XI

The fine filament feed yarns of Example V-11, 12, and 13 were uniformly drawn cold and at 155°C at 1.45X, 1.5X, and 1.55X draw-ratios, respectively, to
5   give nominal 50 denier 100-filament drawn yarns that can be used as flat textile yarns. The drawn fine filament yarns have excellent mechanical quality and along-end denier uniformity with boil-off shrinkages (S) less than about 6%. The cold drawn yarns had
10 slightly less shrinkage than the hot drawn yarns and also were slightly more uniform. With less interlace levels and a different finish, these yarns may be cold drawn air-jet textured, consistent with the teachings of Knox and Noe in U. S. Patent No. 5,066,447. These
15 fine filament spun yarns could also be used as feed yarns for draw air-jet/stuffer-box/friction-twist texturing. Warp draw process and product details are summarized in Table VII.

EXAMPLE XII

20 Examples III-20 through 25 were repeated by varying spin speed and spun denier to provide draw feed yarns capable of being drawn to provide 35 denier 68-filament yarns. Nominal 50 to 60 denier as-spun yarns with excellent mechanical quality and denier uniformity
25 were drawn cold and heat set at 160°C to 180°C to obtain low shrinkage filaments of nominal 0.5 dpf yarns without loss in mechanical quality and along-end denier uniformity. Spin process and product details are summarized in Tables IV and V, and the corresponding
30 draw process and product details are summarized in Table VII.

EXAMPLE XIII

In Example XIII the ability to obtain high T_7
fine filament yarns was explored. Spinning apparatus
similar to that in Example X was used. Poly(ethylene
terephthalate) of nominal 20.8 LRV (0.65 [η])
5 containing 0.3 weight percent TiO_2 was extruded through
9x36 mil (0.229x0.914 mm, 0.0229x0.0914 cm) spinneret
capillaries and cooled using a radial quench apparatus
as described in Example I, except for having a delay
10 length L_{DQ} of about 2.25 inches (5.7 cm). The cooled
filaments were converged into yarn bundles at a
convergence length (L_c) of about 32 inches (81.3 cm)
from the face of the spinneret by use of metered finish
tip guides. The withdrawal speed (V) was varied from
15 4500 ypm (4.12 km/min) to 5300 ypm (4.85 km/min) to
provide 68 and 100-filament direct-use textile yarns
with T_7-values between about 1 and 1.5 g/d. The
process and product details are summarized in Table VI.
The tensiles of Example XIII were inferior due to use
20 of lower polymer melt temperature (T_p) and higher
quench air flow rates (V_a) than in Example X.

EXAMPLE XIV

A 91 denier 100-filament yarn made according
to Example IV was air-jet textured using a Barmag
25 FK6T80 at 300 km/min; wherein, the as-spun yarns were
drawn cold (about 40°C) at 1.0X, 1.1X, 1.2X, and 1.32X
draw-ratios and sequentially air-jet textured using a
conventional air-jet at 125 lbs./in^2 (8.8 kg/cm^2) to
provide bulky yarns with filament deniers between about
30 0.7 and 0.9 (before boil-off shrinkage) and between
about 0.77 and 0.94 dpf (after boil-off shrinkage).
The denier of the textured filament yarn, wherein no
draw was taken, showed an increase in yarn denier of
about 11% due to bulk (e.g., filament loops), where the

ratio (denier)$_{AJT}$/(denier)$_{FLAT}$ is preferably greater than about 1.1); however, the filament denier showed no increase in denier. Textured yarn strengths, as expected, were lower than that of a drawn flat yarn due

5   to the filament loops; but are adequate for bulky fabric end-uses. Even at a 1.32X draw-ratio, giving a textured yarn with a 27.2% residual elongation (corresponding to a 1.27 residual draw ratio RDR), the boil-off (S)and dry heat (DHS) shrinkages were only

10 about 12.7% and 11%, respectively, with a shrinkage shrinkage (ΔS = DHS-S) less than about (1.7%). With heat setting these shrinkages can be reduced to about 2%, if desired. Example XIV-1 and 2 were uniformly cold partially drawn, as defined herein, by providing a

15 RDR of at least about 1.4X in the drawn yarn. The capability of these fine filaments to be uniformly partially drawn is attributed to the crystalline structure of the as-spun filaments providing a thermal shrinkage less than about 12%, preferably less than

20 about 10%, and especially less than about 8%, as per Knox and Noe in U. S. Patent No. 5,066,447. In Example XIV-5 through 8, 68-filament yarns were sequentially draw cold and air-jet textured. The shrinkage increased with draw ratio, providing a route to higher

25 shrinkage AJT yarns. The process and product data for Example XIV is given in Table VIII.

Co-mingling (plying) 2 or more cold drawn AJT yarn textile yarns, wherein at least one AJT yarn has been heat set to shrinkages less than about 3%, and a

30 second AJT yarn has not been heatset, so has significantly higher shrinkage, provides a simplified route to a mixed shrinkage yarn. Similar mixed shrinkage AJT yarns may be provided with the lower shrinkage component provided by alternate techniques,

35 for instance by hot drawing, with or without heat

setting. Alternatively, mixed shrinkage AJT yarns may
be provided by co-mingling 2 or more drawn filament
bundles wherein both bundles are drawn by cold drawing,
without post heat treatment, but the bundles are cold

5   drawn to different elongations, preferably by about 10%
or more. The resulting mixed shrinkage drawn yarn may
be AJT to provide a mixed shrinkage textured (bulked)
yarn. Incorporating filaments of different deniers
and/or cross-sections may also be used to reduce

10   filament-to-filament packing and thereby improve
tactile aesthetics and comfort. Unique dyeability
effects may be obtained by co-mingling drawn filaments
of differing polymer modifications, such as homopolymer
dyeable with disperse dyes and ionic copolymers dyeable

15   with cationic dyes. AJT process and product details
are summarized in Table VIII.

EXAMPLE XV

In Example XV yarns were spun for use as draw
feed yarns (DFY)in false twist texturing (FTT).

20   Example XV-1, a nominal 58 denier 68-filament yarn was
textured at 500 m/min on a L900 PU machine with a 1.707
D/Y-ratio at a 1.628X draw to provide 68-filament
textured yarns of nominal 37 denier (0.54 dpf) with a
tenacity (T) of 4.1 g/d, an elongation-at-break (E_B) of

25   26.8%, a tenacity-at-7%-elongation (T_7) of 2.19 g/d,
and an initial modulus (M) of 44.6 g/d. In Example XV-
2 a nominal 118 denier 200-filament draw feed yarn was
prepared for false twist texturing, as in Example XV-1,
except with a D/Y-ratio of 1.59 at a 1.461X draw-ratio

30   to provide 200-filament textured yarns of 83.5 nominal
denier (0.42 dpf) with a tenacity (T) of about 3.25 g/d
and an elongation-at-break (E_B) of about 23.9%. The
200-filament yarns were also successfully "partially"
warp drawn as per the teachings of Knox and Noe in U.

35   S. Patent No. 5,066,447 with a 1.49X draw-ratio to

provide a nominal 79.6 denier 200-filament flat yarn
having a 4.81 g/d tenacity and a 45.1% elongation-at-
break (E_B). In Example XV-3 a nominal 38 denier 100-
filament yarn was prepared for use as a draw feed yarn

5   in false-twist texturing and in warp drawing. The
process operability for Example XV-3 was better with
6x18 mil (0.152x0.457 mm) capillaries than with 9x36
mil (0.229x0.914 mm) capillaries. The yarns of Example
XV-3 were warp drawn over a range of conditions in

10   Example XVIII to provide 0.22 to 0.27 dpf 100-filament
yarns for wovens and knit fabrics.

EXAMPLE XVI

In Example XVI 21.2 LRV polyester polymer
containing 0.035 weight percent TiO_2 was extruded at

15   285°C through 9x36 mil (0.229 x 0.914 mm) metering
capillaries with a four-diamond-shaped corrugated
ribbon cross-section exiting orifice of area 318 mils^2
(0.205 mm^2). The 80 denier 100-filament bundles were
quenched using radial quench apparatus similar to that

20   used in Example III having a delay length of 2.9 cm and
converged by a metered finish tip applicator at 109 cm
from the face of the spinneret and withdrawn at a spin
speed of 2350 ypm (2.15 km/min). Yarns quenched with
47.5 mpm room temperature air had a along-end denier

25   spread (DS) of about 1.6-1.8%, a BOS of about 2.8%, an
average elongation-at-break (E_B) of 92.9% , an average
tenacity-at-break (T_B) of 4.56 g/d to give a $(T_B)_n/T_7$-
ratio of about 4.3. Decreasing quench air velocity to
21.7 m/min increased the T_B to about 4.64 g/d with a

30   $(T_B)_n/T_7$-ratio of about 4.5. The lower T_B-values
(i.e., less than about 5) are a consequence of the
corrugated filament cross-sectional shape and such
filaments may be used in processes, such as false-twist
texturing (FTT) and air-jet texturing (AJT) where

35   filament fracture is desired to give even finer

filaments (i.e., even less than about 0.2 dpf) for a
more spun-like aesthetics.

EXAMPLE XVII

5   In Example XVII nominal 43 denier 50-
filaments with a concentric void of about 16-17% were
spun at 3500 ypm (3.2 km/min) and at 4500 ypm (4.12
km/min). The hollow filaments were formed by post-
coalescence of nominal 21.2 LRV polymer at 290°C using
segmented capillary orifices with 15x72 mil
10   (0.381x1.829 mm) metering capillaries as essentially
described by Champaneria etal in U. S. Patent No.
3,745,061, Farley and Barker in Br. Patent No.
1,106,263, Hodge in U. S. Patent No. 3,924,988 (Figure
1), Most in U. S. Patent No. 4,444,710 (Figure 3), in
15   Br. Pat. Nos. 838,141, and 1,106,263. The geometry of
the entrance capillary (counterbore) to the segmented
orifices was adjusted to optimize the extrudate bulge
and minimize pre-mature collapse of the hollow melt
spinline. The ratio of the inner and outer diameters
20   of the circular cross-section formed by the segmented
orifices was adjusted to provide percent void content
greater than about 10% and preferably greater than
about 15%. The void content is found to increase with
extrusion void area ($\pi ID^2/4$), mass flow rate, polymer
25   melt viscosity (i.e., proportional to LRV/T_p) and with
increasing withdrawal speed (V) and the above process
parameters are selected to obtain at least about 10%
and preferably at least about 15% void content (VC).
For example the fine hollow filaments were quenched
30   using radial quench apparatus fitted with a short delay
shroud as described in Example XVI, except air flow was
reduced to about 16 m/min and converged via a metered
finish tip applicator at a distance less than about 140
cm. The yarns spun at 3.2 km/min had
35   tenacity/elongation/modulus of about 3 gpd/90%/45 gpd,

respectively and a tenacity-at-7%-elongation (T_7) of
about 0.88 g/d. Yarns spun at 4.115 km/min had
tenacity/elongation/modulus of about 2.65 gpd/46%/64
gpd, respectively, and a tenacity-at-7%-elongation (T_7)

5   of about 1.5 g/d. Yarns spun at 3.2 and 4.12 km/min
had boil-off shrinkage (S) values between about 3-5%.

EXAMPLE XVIII

In Example XVIII, the spun yarns of Example
XV-3 were drawn over a range of draw-ratios from 1.4X

10   to 1.7X to provide drawn filament yarns of deniers 26.6
to 22.2, respectively; with tenacities increasing from
4.38 g/d to 5.61 g/d and elongations-at-break (E_B)
decreasing from 36.6% to 15.8% with increasing draw-
ratio. All the draw yarns had boil-off shrinkages (S)

15   of about 4%. See Table VIII for process and product
summery.

EXAMPLE XIX

In Example XIX-1 and XIX-2, 200-filament and
168-filament yarns (feed yarns from Example XV-3 and 4,

20   repsectively) of nominal 0.5 dpf were spun at 4400 ypm
(4.02 km/min) for use as direct-use flat yarns in woven
and knit fabrics. These yarns can also be air-jet
textured (AJT) without draw to provide low-shrinkage
AJT yarns of nominal 3% shrinkage.

25   ## EXAMPLE XX

In Example XX mixed filament yarns were
prepared by co-spinning sub denier filaments of the
invention with higher denier filaments, such as the low
shrinkage filaments as described by Knox in U. S.

30   Patent No. 4,156,071 and/or the high shrinkage
filaments described by Piazza and Reese in U. S. Patent
No. 3,772,872 to provide the potential for mixed-

shrinkage (e.g., post-bulking in fabric) such as in the
case when the low shrinkage filaments of this invention
are combined with the high shrinkage filaments of
Piazza and Reese. On-line thermal treatment by use of
5   a heated tube or a steam jet, wherein essentially no
reduction in filament denier takes place (i.e., no
space drawing) of mixed dpf low shrinkage filament
yarns, such as those prepared by co-spinning filaments
of this invention with those as described by Knox in U.
10   S. Patent No. 4,156,071, provides a route to unique
mixed shrinkage post-bulkable filament yarns wherein
the shrinkage of the sub denier filaments of this
invention remain essentially unchanged while the
shrinkage of the higher denier filaments (e.g., 2-4
15   dpf) is increased from initial boil-off shrinkage (S)
of less than about 6-10% to greater than 10%, typically
about 15-35%. The mixed shrinkage yarns prepared with
the mentioned intermediate heat treatment differ from
those obtained by combining the low shrinkage filaments
20   of this invention with the higher shrinkage filaments
of Piazza and Reese in that the heat treated high
shrinkage filaments have significantly improved
shrinkage tension (e.g., at least about 0.15 g/d) which
permits development of the bulk from the mixed-
25   shrinkage even in very tightly constructed woven
fabrics.

        The combination of high shrinkage and high
shrinkage tension (herein called shrinkage power) was
heretofore only obtained, for example, by fully drawing
30   conventional LOY/MOY/POY followed by no or low
temperature annealing. The sub denier filaments of the
invention migrate to the surface on mixed shrinkage and
provide a soft luxurious tactile aesthetics even in the
most tightly constructed fabrics. The heat treatment
35   is typically carried out after the filaments are fully
attenuated and quenched to below their glass transition

temperature and in a manner that the increase in
tension during the heat treatment is of the magnitude
equal to that of the observed increase in shrinkage
tension by said heat treatment. Selecting heat
treatment conditions greater than about the cold
crystallization temperature $T_{CC}(DSC)$, (typically about
95 to about 115°C) and less than about the temperature
of maximum crystallization T_C (typically about 150 to
about 180°C for most polyesters) gives high shrinkage
tension filaments of excellent dyeability (e.g., high
RDDR), while treatment under temperatures greater than
T_C gives high shrinkage tension filaments of reduced
dyeability. The filaments may be heated either by
passing through high pressure superheated steam (e.g.,
40-140 psi at about 245°C) or by passing through a
heated tube. The high and low dpf filaments may be
spun from separate pack cavities and then combined to
form a single mixed-dpf filament bundle or may be spun
from a single pack cavity, wherein the capillary
dimensions (L and D) and the number of capillaries $\#_C$
are selected to provide for differential mass flow
rates; e.g., by selecting capillaries such that the
ratio of spun filament deniers, $[(dpf)_b/(dpf)_a]$, is
approximately equal to $[(L_aD_b/L_bD_a)^n \times (V_a/V_b) \times (D_b/D_a)^3]$, where a and b denote filaments of differing
deniers; n = 1 for Newtonian polymer melts (and herein
determined experimentally from convetnional capillary
pressure drop tests) and that the measured average dpf
= $[(\#_a dpf_a + \#_b dpf_b)/(\#_a + \#_b)]$. The above heat
treatment process can also be used to increase the
lower shrinkage of the sub denier filaments of the
invention as defined by the needs of the particular
end-use, such as increasing from about 3% to about 6-8%
with higher shrinkage tension (and shrinkage power) for
tightly constructed wovens.

EXAMPLE XXI

In Example XXII 50 denier 68-filament undrawn
flat textile yarns were uniformly cold drawn and heat
treated at 160, 170, and 180°C to provide nominal 36
5   denier 50 filament drawn yarns of about 4-5% boil-off
shrinkage (S) with a T_7 of about 3.5 g/d, a tenacity of
about 4.5 g/d with an elongation-at-break (E_B) of about
27%. The drawn yarns have a percent Uster of about
2.1-2.4% and may be used for critically dyed fabrics.

10   ## EXAMPLE XXII

The fine denier filaments of this invention
may be used to cover elastomeric yarns (and tapes) by
high speed air-jet entanglement as taught by Strachan
in U. S. Patent No. 3,940,917. Polyester fine
15   filaments prepared from polymer modified for cationic
dyeability are especially suitable for elastomeric
yarns, such as Lycra® to prevent "bleeding" of the
dyestuff from the elastomeric yarns, such as observed
for Lycra® covered with homopolymer polyester dyed with
20   nonionic disperse dyes. The direct-use filaments of
this invention are preferred (and those with increased
shrinkage, shrinkage tension, and shrinkage power as
described in Example XX are especially preferred) for
air-entanglement covering and permit the covered
25   elastomeric yarns to be dyed under atmospheric
conditions without the use of carriers, e.g., similar
to the dye bath conditions to dye nylon filament
covered elastomeric yarns (except for being dyed with
anionic acid dyes).

30   Some example fabrics made from the yarns of
the invention are: 1) a medical barrier fabric
constructed with a low shrinkage 70 denier 100-filament
direct-use flat yarn filling and a 70 denier 34-

filament conventional warp drawn POY in the warp and woven on a high speed water-jet loom at 420 picks per minute to give a plain weave fabric of 164 ends per inch in the warp and 92 picks per inch in the fill; 2)

5   a lounge wear satin constructed using the above 70 denier 100-filament direct-use yarn in the warp and combining it with a 60 denier 100-filament false twist textured fill to provide a satin with 172 ends per inch in the warp and 100 picks per inch in the fill; and 3)

10   a crepe de chines fabric constructed with the above 70 denier 100-filament direct-use yarn in the warp and a 2-ply 60 denier 100-filament false twist textured yarn in the fill.

            For convenience the symbols, conversions, and

15   analytical expressions used herein before are listed below:

PET	Poly(ethylene terephthalate)
2GT	PET
TiO_2	Titanium dioxide
SiO_2	Silicon dioxide
$(\ )_f$	"of the fiber"
$(\ )_p$	"of the polymer"
$(\ )_m$	"measured"
dpf	Denier per Filament (1 gram/9000 meters)
dpf(ABO)	DPF after boil-off shrinkage
dpf(BBO)	DPF before boil-off shrinkage
DS	Along-end % Denier Spread (±3 sigma)
DTV	Draw tension variation (%)
$[\eta]$	Intrinsic Viscosity (IV)
LRV	Relative Viscosity (Lab)
IV	Intrinsic Viscosity
$LRV_{20.8}$	LRV of the polyester polymer having the same melt zero-shear Newtonian melt viscosity as homopolymer (unmodified

2GT) of 20.8 LRV at 295 degrees cenitgrade (C)

C	Degrees centigrade
η_a	Apparent melt viscosity (poise)
5 η_o	Melt viscosity as shear rate -> 0
X	Weight fraction of delusterant
T_M^o	Zero-shear polymer melting point (°C)
$(T_M)_a$	Apparent melting point of polymer (°C)
T_g	Polymer glass-transition temp.(°C
10 T_p	Polymer melt spin temperature (°C)
T_a	Quench air temperature (°C)
T_s	Spinline surface temperature
t_r	Filtration residence time (min)
w	Capillary mass flow rate (gpm)
15 q	Capillary volume flow rate (cm^3/min)
Q	Spin pack flow rate (gpm)
$\#_c$	Number of filaments per spin pack
V_F	Spin pack (filled) free-volume (cm^3)
L	Capillary Length (cm)
20 L/D_{RND}	Capillary Length-Diameter Ratio
D_{RND}	Capillary Diameter equal to round capillary of equal x-section area (A_c)
D_{ref}	Diameter of reference spinneret
D_{sprt}	Diameter of test spinneret
25 A_c	Capillary cross-sectional area (cm^2)
G_a	Apparent capillary shear rate (sec^{-1})
ε_a	Apparent spinline strain
E_R	Apparent spinline extension ratio
EFD	Extrusion filament density
30 dV/dx	Velocity gradient
σ_a	Apparent internal spinline stress (g/d)
V_a	Quench air laminar velocity (m/min)
L_{DQ}	Quench delay length (cm)
L_c	Convergence length (cm)
35 V_c	Spin speed at convergence (km/min)
V	Spin (withdrawal) speed (km/min)

	V_O	Capillary Extrusion velocity (m/min)
	A_O	Spin pack extrusion area (cm^2)
	dV/dx	Spinline velocity gradient (min^{-1})
	η	Melt viscosity (poise)
5	DQ	Delay quench
	$(\ )_N$	Measured at the "neck" point
	ypm, y/min	yards per min
	mpm, m/min	meter per min
	gpm, g/min	grams per min
10	ρ_m	Measured fiber density (g/cm^3)
	ρ_c	Fiber density corrected for delusterant
	ρ_a	Amorphous density (1.335 g/cm^3)
	ρ_x	Crystal Density (1.455 g/cm^3)
	X_V	Volume fraction crystallinity
15	X_w	Weight fraction crystallinity
	S	Percent boil-off shrinkage
	DHS	Percent dry heat shrinkage
	ΔS	Shrinkage Differential (DHS-S)
	S_m	Maximum shrinkage potential (%)
20	ST	Shrinkage Tension (g/d)
	ST_{max}	Maximum shrinkage tension (g/d)
	$T(ST_{max})$	Shrinkage tension peak temperature (°C)
	P_S	Shrinkage power (g/d)(%)
	T_{SET}	Maximum set temperature
25	Mi	Instantaneous tensile modulus (g/d)
	M	Initial (Young's) tensile modulus (g/d)
	M_{py}	Post yield modulus (g/d)
	T_7	Tenacity-at-7%-elongation (g/d)
	T_{20}	Tenacity-at-20%-elongation (g/d)
30	T	Tenacity (g/d)
	T_B	Tenacity-at-break (g/dd)
	$(T_B)_n$	Normalized T_B (g/d)
	gpdd, g/dd	Grams per drawn denier
	gpd, g/d	Grams per (original undrawn) denier
35	SF	Shape Factor (= P_M/P_{RND})
	P_M	Measured perimeter (P)

	P_{RND}	P of round filament of equal area
	RDDR	Relative Disperse Dye Rate ($min^{1/2}$)
	DDR	Disperse Dye Rate ($min^{1/2}$)
	RDR	Residual Draw-Ratio
5	1.abX	Draw-ratio of value "1.ab", for example
	E_B	Elongation-at-Break (%)
	tan α	Secant post-yield modulus (g/d)
	tan β	Tangent post-yield modulus (g/d)
	Δ_n	Birefringence
10	Δ_a	Birefringence of amorphous regions
	Δ_c	Birefringence of crystalline regions
	Δ^o	Intrinsic Birefringence
	SOC	Stress-Optical Coefficient $(gpd)^{-1}$
	f_a	Amorphous orientation function
15	f_c	Crystalline orientation function
	COA	Crystal orientation angle (WAXS)
	LPS	Long Period Spacing (SAXS, Å)
	CS	Average (WAXS, 010) crystal size (Å)
	Tcc (DSC)	DSC- cold crystallization temp., (°C)
20	T(E"max)	E" peak temperature (T_α)
	E"	Dynamic loss modulus (g/d)
	M_{son}	Sonic Modulus (g/d)
	M_S	Shrinkage Modulus (g/d)
	SV	Sonic velocity (km/min)
25	$V_{f,am}$	Amorphous free-volume ($Å^3$)
	Å	Angstroms
	mil	0.001 inhes = .0254 mm = 25.4 microns
	μ	Micron (10^{-6} m = 10^{-4} cm = 10^{-3} mm)
	km/min	kilometers/min = 10^3 meters/minute
30	A	Hydrocarbolenedioxy units [-O-R'-O-]
	B	Hydrocarbolenedicarbonyl units [-C(O)-R"-C(O)-]
	R', R"	hydrocarbolene group
	C,H,O	Carbon, hydrogen, and oxygen
35	-O-	"Oxy" (ether) linkage
	-C(O)-	Carbonyl group

	RPC	Rapid Pin Count
	FOY	Percent weight finish-on-yarn
	AJT	Air-jet texturing
	LOY	Low-oriented yarns
5	MOY	Medium-oriented yarns
	HOY	Highly oriented yarns
	POY	Partially-oriented yarns
	SOY	Spin-oriented yarns
	DUY	Direct-use yarns
10	FDY	Fully drawn yarns
	PBY	Post-bulkable yarns
	WDFY	Warp draw feed yarn
	DFY	Draw feed yarn
	DTFY	Draw texturing feed yarn
15	FTT	False-twist texturing
	SBC	Stufer-box crimping
	SBT	Stuffer-box texturing
	SDSO	Simplified direct spin-orientation
	WAXS	Wide-angle x-ray scattering
20	SAXS	Small-angle x-ray scattering
	DSC	Differential Scanning Calorimetry
	RAD	Radial quench
	XF	Cross-flow quench
	DT	Draw tension (gpd)
25	DTV	Draw tension variation (%)
	IFDU	Interfilament denier uniformity
	RND	Round
	TRI	Trilobal
	RIB	Ribbon
30	HOL	Hollow
	ABO	After boil-off shrinkage
	BBO	Before boil-off shrinkage
	RV	Relative Viscosity
	FVC	Fractional void content
35	EVA	Extrusion void area
	ID	Inner diameter

	OD	outer diameter
	d	diameter of filament (cm)
	N_{iso}	Isotropic index of refaction
	HRV	LRV + 1.2
5	RV	1.28(HRV)
	$(\eta_o)_{2GT}$	$[0.0653(LRV + 1.2)^{3.33}]$ at 295°C
	$(\eta_o)_{Tp}$	$(\eta_o)_{295°C} \times (295/T_p)^6$
	ft^3	0.0284 m^3
	μ (micron)	10^{-4} cm
10	mil (0.001")	2.54×10^{-3} cm = 25.4 microns
	m/min	0.9144 yd/min
	dpf	1 gram/9000 meters
	g/min	0.132 pph
	d(cm)	$11.89 \times 10^{-4}(dpf/\rho)^{\frac{1}{2}}$
15	$(T_M)_a$	$(T_M)^0 + 2 \times 10^{-4}(L/D)G_a$, °C
	G_a (sec^{-1})	$(32/60\pi)(w/1.2195)(1/D_{RND})^3$, sec-1
	t_R (min)	$[1.2195\ V_F(cm^3)]/(w\ \#_c)$, min
	σ_a	$10^{-3}(\rho/SOC)(LRV/LRV_{20.8})(T_R/T_p)^6$ $[V^2/dpf][A_o(cm)/\#_c]^{0.7}$, g/d
20	E_R	$V/V_o = 2.25 \times 10^5(1.2195\pi)(D_{RND}^2/dpf)$
	ε_R	$Ln(E_R)$
	T_s	$660(wL/D^4)^{0.685}$, °C; wherein W = pph and L and D are in mils
	T_R	$(T_M)_a + 40°C$
25	w	dpf V(mpm)/9000 = dpf V(km/min)/9, g/min
	D_{RND}	$2(A_c/\pi)^{1/2}$, cm
	X_v	$(\rho-\rho_a)/(\rho_c-\rho_a)$
	X_w	$(\rho_c/\rho)X_v$
	ρ_c	1.455 g/cm^3
30	ρ_a	1.335 g/cm^3
	ρ_{cor}	$\rho_{measured} - 0.0087(\%TiO_2)$, g/cm^3
	ΔS	(DHS,% - S,%)
	S_M	$(550-E_B,\%)/6.5$, %
	M_{py}	$(1.2T_{20} - 1.07T_7)/(1.2-1.07)$, g/d
35	T_B	(Tenacity,T)(RDR), g/d
	RDR	$(1 + E_B,\%/100)$,

$(T_B)_n$ $T_B \times LRV^{0.75}(1-X)^{-4}$

Δ_n $\Delta_c + \Delta_a = \Delta^o[X_v f_c + (1-X_v)f_a]$

f_c $(1 - COA/180)$

f $\Delta_n/\Delta^o \doteq \frac{1}{2}(3<cos>^2 - 1)$

5   Δ^o 0.220

SOC $\Delta_n/\sigma_a = 0.7 \ (g/d)^{-1}$

$V_{f,am}$ $CS^3[(1-X_v)/X_v][1-f_a]/f_a], \ \text{Å}^3$

$\Delta P =$ $4(L/D_{RND})^n \eta_a G_a, \ n = 1$ for Newtonian
               melts and as $G_a \to 0$

10   $(dpf)_b(dpf)_a$ $[(L/D)_a/(L/D)_b]^n[(V_a/V_b)(D_b/D_a)^3$

ΔP $4(L/D)\eta_a G_a = 4(L/D)\tau_{wall}$

τ_{wall} $\eta_a G_a$

G_a $(32/\pi\rho)(w/D^3), \ sec^{-1}$

V_o $(w/\rho)/(Area), \ cm/min$

15   g/d $1.0893N/dtex$

$1 \ g$ 0.9804×10^3 dynes

$1 \ N$ 10^3 dynes

PSI $0.0703 \ kg/cm^2$

g/cm^2 $0.9(\rho)(g/d) = (\rho)(g/dtex)$

20   EVA $\pi(ID^2/4)$

FVC $(ID/OD)^2$

P_S $(ST, \ g/d) \times (S,\%)$

ABO $BBO[100/(100-S)]$

TABLE I

EX.-ITEM	1-1	1-2	1-3	1-4	2-1	2-2	2-3	2-4	2-5	2-6	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11
POLYMER																					
LRV	19	→	→	→	20.8	→	→	→	→	→	21.2	→	→	→	→	→	→	→	→	20.8	21.2
TiO2,%	.30	→	→	→	.10	→	→	→	→	→	.035	→	→	→	→	→	→	→	→	.030	.035
FIL/YARN																					
dpf	.53	.52	.49	.51	.74	.99	.94	.75	.63	.50	.73	→	→	→	→	→	.88	.51	.76	.49	.51
# Fils	300	100	300	100	68	100	80	100	80	100	68	→	→	→	→	→	60	35	→	33	35
Yarn Denier	158	51.7	148	50.6	50	99	75	75	50	100	→	→	→	→	→	→	→	→	51.5	→	→
EXTRUSION																					
TP, °C	290	290	295	295	299	301	300	→	299	→	288	→	→	→	→	289	289	300	288	294	290
#/Ro, cm^-2	12.6	4.2	12.6	4.2	2.8	4.2	3.3	4.2	3.3	4.2	2.8	→	→	→	→	→	→	→	→	→	→
w, g/min	.188	.185	.225	.233	.300	.402	.382	.305	.256	.203	.282	.297	.312	.326	.341	.282	.224	.233	.332	.224	.241
q, cm^3/min	.155	.152	.185	.191	.246	.330	.313	.250	.210	.167	.231	.244	.256	.268	.280	.231	.184	.191	.272	.184	.198
tr, min	1.05	3.22	0.88	2.57	2.93	1.48	1.96	1.96	2.92	2.93	3.12	2.95	2.81	2.69	2.57	3.12	3.92	3.77	4.11	3.92	3.64
L, mils	9	60	9	60							20										
L, cm x10	.229	1.52	.229	1.52							.508							50			
DRND, mils	6	15	6	15							9										
DRND, cm x10	.152	.381	.152	.381							.229							1.27			
L/DRND	1.5	4	1.5	4							2.22										
RC, mils^2	28.3	176.8	28.3	176.8							63.6							5.56			
RC,cm^2 x10^3	.182	1.14	.182	1.14							.411										
Go, sec^-1	7389	465	8844	586	755	1011	961	767	644	511	3284	3459	3634	3797	3971	3284	2609	2714	3867	2609	2807
(L/DRND)Gox10^-1	1108	186	1327	234	302	404	384	397	258	204	729	658	807	842	471	729	579	1509	2151	1451	1561
K(L/DRND)Go, °C	2.2	0.4	2.7	0.5	0.6	0.8	0.7	0.8	0.5	0.4	1.4	1.3	1.6	1.7	0.9	1.4	1.2	3.0	4.3	2.9	3.1
QUENCHING																					
LDo, cm	2.5	2.5	4.8	→	5.7						6.7										
121dpf, cm	8.7	8.7	7.6	8.6	10.1	11.9	11.6	10.4	9.5	8.5	10.3						11.3	8.6	10.5	8.4	8.6
Va, m/min	21.3										13.1					16.3		21.3		18.9	13.1
Lc, cm	137				126	140	137	128	121	114	109						135	115	129	113	114
50:90Jdpf,cm	116	115	117	114							127										
SPINNING																					
U, y/min	3500	3500	4500	4500	4000	→	→	→	→	→	3800	4000	4200	4400	4600	3800	2500	4500	4300	4500	4650
V, m/min	3200	3200	4115	4115	3658	→	→	→	→	→	3475	3658	3841	4024	4206	3475	2286	4115	3932	4115	4252
ER(=V/Vo)	378	2407	409	2455	1692	1265	1332	1669	1987	2504	617						512	884	593	920	884
Ee [=ln(ER)]	5.93	7.79	6.01	7.81	7.43	7.14	7.19	7.42	7.59	7.83	6.43	6.94	7.59	8.36	9.00	5.79	6.24	6.78	6.39	6.82	6.78
EanF7, g/d	5.34	9.82	7.03	10.3	6.76	5.89	6.04	7.20	7.59	7.83	6.43						3.18		6.90	9.34	8.81
YARN																					
S, %	55	35	11.2	7.4	25	11	7	12			--	--	--	2.9	--	3.7	--	--	3.3	4.6	--
Ni, g/d	43	55	59	65	45	37	36	38			--	--	--	--	--	--	--	--	--	71.6	--
T7, g/d	0.90	1.26	1.17	1.32	0.91	0.84	0.84	0.97			1.00	1.08	1.18	1.30	1.40	0.90	0.51	--	1.08	1.37	1.30
EB, %	85	63	76	62	66	81	86	77			101	94.1	94.2	87.4	79.6	99.7	136.8	--	--	54.5	71.0
T, g/d	3.0	3.1	3.6	3.4	3.1	3.3	3.4	3.5			3.14	3.12	3.21	3.12	3.09	3.29	2.98	--	--	3.02	2.97
TB, g/d	5.55	5.05	6.34	5.51	5.15	6.08	5.58	6.20			6.32	6.06	6.23	5.85	5.55	6.57	7.06	--	--	4.67	5.08
(TB)n, g/d	5.77	5.57	6.87	5.97	5.68	7.14	5.60	6.23			6.23	5.98	6.11	5.77	5.47	6.48	6.96	--	--	4.69	5.01
(TB)n/T7	6.41	4.42	5.87	4.52	3.5	2.7	2.0	3.5			6.23	5.53	5.17	4.43	3.90	7.20	13.6	--	1.3	3.42	3.05
DS,%	--	--	--	--	--	--	--	--			1.24	1.22	1.26	1.26	1.35	1.69	1.56	1.3	1.0	--	1.42
DIV, %	--	--	--	--	--	--	--	--			0.29	0.21	0.26	0.26	0.21	0.34	0.50	--	--	--	0.37
BFS	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES

TABLE II

EX.-ITEM	3-12	3-13	3-14	3-15	3-16	3-17	3-18	3-19	3-20	3-21	3-22	3-23	3-24	3-25	4-1	4-2	4-3	4-4	4-5	4-6	4-7
POLYMER																					
LRV	21.2	→	→	→	→	→	→	→	→	→	→	→	→	→	→	21.1	20.6			20.6	—
TiO$_2$, %	.035	→	→	→	→	→	→	→	→	→	→	→	→	→	→	.30	1.0			1.0	—
FIL/YARN																					
dpf	.51	→	→	→	.89	.75	.70	.69	.88	.88	.83	.75	.75	.75	.70	→	→	→	→	.70	—
# Fils	136	→	→	→	68	→	→	→	→	→	→	→	→	→	100	→	→	→	→	100	—
Yarn Denier	70	→	→	→	60.6	50.8	50.8	50.4	60.6	60.6	60.6	56.1	50.9	50.8	70	→	→	→	→	70	—
EXTRUSION																					
TP, °C	291	→	287	287	287	291	291	288	→	→	→	→	→	→	→	288				288	—
θ/Ro, cm^{-2}	5.6				2.8										4.2	4.2				4.2	—
w, g/min	.209	.225	.246	.225	.244	.229	.235	.225	.244	.263	.260	.259	.274	.298	.331	.327	.327	.270	.285	.299	.313
q, cm^3/min	.172	.185	.202	.185	.200	.187	.192	.185	.200	.216	.213	.213	.225	.244	.271	.254	.254	.222	.233	.245	.257
tr, min	3.25	3.02	2.77	3.02	3.60	3.85	3.75	3.90	3.60	3.34	3.38	3.37	3.21	2.95	1.81	1.93	1.93	2.21	2.10	2.00	1.91
L, mils	36							20							36					36	
L, cm x10	.914							.508							.914					.914	
DRMD, mils	9																			9	
DRMD, cm x10	.229																			.229	
L/DRMD	4							2.22							4					4	
RC, mil^2	63.6																			63.6	
RC, cm^2 x10^3	.411																			.411	
Bo, sec^{-1}	2435	2621	2865	2621	2843	2668	2738	2620	2842	3063	3028	3028	3191	3471	3856	3810	3810	3146	3321	2494	3646
(L/DRMD)Bo×10^{-1}	974	1049	1146	1049	1137	1067	1095	582	631	681	673	673	709	771	1543	1524	1524	1258	1328	1393	1459
k(L/DRMD)Bo, °C	1.9	2.1	2.3	2.1	2.3	2.1	1.2	1.2	1.3	1.4	1.4	1.4	1.5	3.1	3.1	3.0	3.0	2.5	2.7	2.8	2.9
QUENCHING																					
LDQ, cm	6.7				11.3	10.4	8.4	11.3	11.3	11.3	10.9	10.4	10.4	10.4	8.4	21.2				6.7	
(12)dpf, cm	8.6															13.1	13.1			8.1	
Vo, m/min	30.6																			13.1	
Lc, cm	109																			109	
S(b190)dpf, cm	115				135	128	125	135	135	135	132	128	128	125	125					125	
SPINNING																					
V, y/min	4000	4300	4700	4300	2700	3000	3300	2500	2700	2900	3108	3400	3600	3800	4650	4600	4600	3800	4000	4200	4400
v, m/min	3658	3932	4298	3932	2469	2743	3018	2286	2469	2652	2835	3109	3292	3475	4252	4206	4206	3475	3658	3840	4023
ER(=V/Vo)	884	506	506	506	610	644	644	506	506	506	546	603	603	603	644	—		644	644	644	—
εo [=lnERD]	6.78	7.46	8.61	6.23	6.41	6.47	6.47	6.22	6.22	6.22	6.30	6.40	6.40	6.40	6.47	8.35	7.44	6.15	6.21	6.47	6.60
εsx17, g/d	6.92			7.79	3.72	3.82	4.21	3.17	3.36	3.61	4.22	4.99	5.38	5.82	7.96		6.15	6.60		6.60	7.18
YARN																					
T7, g/d	1.02	1.10	1.27	1.25	0.58	0.59	0.65	0.51	0.54	0.58	0.67	0.78	0.84	0.90	1.23	1.29	1.15	0.95	0.96	1.02	1.11
EB, %	82.7	76.1	69.8	70.1	127.5	104.8	108.3	143.8	139.2	133.2	128.3	107.1	110.2	105.1	69.9	82.8	82.3	102.6	97.2	91.8	87.0
T, g/d	3.22	3.20	3.19	3.12	2.73	2.52	2.95	2.97	3.05	3.10	3.25	3.31	3.37	3.34	3.34	3.00	2.90	2.95	2.95	2.93	2.91
TB, g/d	5.88	5.63	5.42	5.31	6.20	5.16	6.14	7.24	7.30	7.23	7.42	6.78	6.96	7.05	5.67	5.48	5.29	5.98	5.82	5.62	5.44
(TB)n, g/d	5.82	5.57	5.37	5.26	5.11	5.11	6.08	7.17	7.23	7.16	7.35	6.71	6.89	6.98	5.61	5.37	5.18	6.10	5.70	5.51	5.33
(TB)n/T7	5.70	5.06	4.22	4.20	10.5	8.66	9.35	14.0	13.3	12.3	10.9	8.60	8.20	7.75	4.56	4.16	4.50	6.42	5.93	5.40	4.80
DS, %	1.17	1.36	1.72	1.61	0.99	1.06	1.03	1.56	1.54	1.48	1.68	1.71	1.63	1.69	1.7	1.46	2.01	2.10	2.07	2.08	1.98
DTU, %	0.22	0.36	0.28	0.33	0.53	0.40	0.46	0.67	0.65	0.47	0.34	0.52	0.52	0.34	—	—	0.44	0.52	0.44	0.47	0.42

TABLE III

EX.-ITEM	4-8	4-9	5-1	5-2	5-3	5-4	5-5	5-6	5-7	5-8	5-9	5-10	5-11	5-12	5-13	6-1	6-2	6-3	6-4	6-5	6-6
POLYMER	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
LRV	20.6	→	21.1	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	21.1	→	→
TiO2, %	1.0	→	.30	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	0.3	→	→
FIL/YARN																					
dpf	.70	→	.85	→	→	→	→	→	.77	.78	.76	.76	.83	.76	.69	.42	.56	.75	.42	.56	.75
# Fils	100	→	→	→	→	→	→	→	→	→	→	→	→	→	→						
Yarn Denier	70	→	85	→	→	→	→	→	77	78	76	76	83	76	69	42	56	75	42	56	75
EXTRUSION																					
TP, °C	288	→	286	287	→	→	287	292	287	287	→	→	291	→	→	→	→	→	→	→	→
#/Ro, cm^-2	4.2																				
w, g/min	.316	.358	.207	.233	.259	.265	.259	.259	.258	.262	.255	.255	.232	.245		.141	.188	.252	.141	.188	.252
q, cm3/n	.260	.293	.170	.191	.212	.234	.212	.212	.212	.214	.209	.209	.190	.201		.115	.154	.206	.115	.154	.206
tr, min	1.88	1.67	2.88	2.57	2.31	2.09	2.31	→	2.29	2.29	2.34	→	2.95	2.58	2.44	4.26	3.18	2.38	4.26	3.18	2.38
L, mils	36	→	50	→	→	→	36	18	36	→	50	→	36	→	→						
L, cm x10	.914	→	1.27	→	→	→	.914	.457	.914	→	1.27	→	.914	→	→						
DRND, mils	9	→	12	→	→	→	9	6	9	→	12	→	9	→	→						
DRND, cm x10	.229	→	.305	→	→	→	.229	.152	.229	→	.305	→	.229	→	→						
L/DRND	4	→	4.17	→	→	→	4	3	4	→	4.17	→	4	→	→						
RC, mil^2	63.5	→	113.1	→	→	→	63.6	28.3	63.6	63.6	113.1	→	63.6	→	→						
RC, cm^2 x10^3	.411	→	.731	→	→	→	.411	.182	.411	.411	.730	→	.411	→	→						
Ga, sec^-1	3681	4169	1016	1144	1272	1399	3017	10181	3006	3052	1252		2352	2703	2854	1643	2190	2936	1643	2190	2936
(L/DRND)Gax10^-1	1473	1668	424	477	530	584	1207	4072	1202	1221	522	941		1081	1142	657	876	1174	657	876	1174
k(L/DRND)Ga x10, °C	2.9	3.3	0.8	0.9	1.1	1.2	2.4	8.1	2.4	2.4	1.0	1.9		2.1	2.2	1.3	1.7	2.3	1.3	1.7	2.3
QUENCHING																					
LDQ, cm	6.	→	11.1	→	→	→	→	→	10.5	11.8	11.8	6.7	6.7	10.4	→	10.0	9.0	10.4	7.8	9.0	10.4
12Idpf, cm	8.4	→	11.1	→	→	→	→	→	10.5	11.8	11.8	6.7	6.7	10.9	10.4	7.8	9.0	10.4	7.8	9.0	10.4
Va, m/min	13.1	→	25	→	→	→	→	→	→	→	16.3	→	21	19	→	16.3					
Lc, cm	109	→	133	→	→	→	→	→	→	→	→	→	132	129	124	108	117	128	108	117	128
SD198Idpf, cm	125	→	133	→	→	→	→	→	129	129	→	→	132	129	124	108	117	128	108	117	128
SPINNING																					
V, y/min	4450	4600	2400	2700	3000	3300	3000	—	3300	3300	—	—	2400	3000	3300	—	—	—	—	—	—
V, m/min	4069	4206	2195	2469	2743	3018	2743	—	3018	3018	—	—	2195	2743	3018	—	—	—	—	—	—
Vo, m/min	644	—	943	—	530	236	585	—	1054	—	543	593	653	—	—	1073	805	601	1073	805	601
ER(=V/Vo)	5.47	—	6.85	5.14	5.62	6.58	6.27	5.46	6.37	6.96	6.30	6.39	6.40	→	→	6.98	6.69	6.40	6.98	6.69	6.40
Ea [=ln(ER)]	7.38	7.44	4.38	5.62	6.27	5.27	4.48	6.12	5.92	6.68	6.61	5.86	6.22	6.29	6.29	5.69	6.40	6.29	5.69	6.40
EaaT7, g/d	7.38	7.44	4.38	5.14	5.62	6.58	5.27	4.48	6.12	5.92	6.68	6.61	5.86	6.22	6.29	—	—	—	—	—	—
YARN																					
T7, g/d	1.14	1.15	0.64	0.75	0.82	0.96	0.84	0.82	0.96	0.93	0.96	0.95	0.93	0.96	0.97	—	—	—	—	—	—
EB, %	86.0	82.3	136.2	124.9	118.0	104.1	116.2	117.8	103.9	107.4	103.8	104.7	106.8	104.2	103.0	—	—	—	—	—	—
T, g/d	2.91	2.90	2.83	2.98	3.08	3.11	2.98	2.64	3.14	3.16	3.19	3.15	3.20	3.30	3.30	—	—	—	—	—	—
IB, g/d	5.38	5.29	6.68	6.70	6.71	6.35	6.27	5.75	6.40	6.55	6.50	6.45	6.62	6.74	6.70	—	—	—	—	—	—
(IB)N, g/d	5.59	5.50	6.65	6.61	6.62	6.26	6.18	5.67	6.31	6.46	6.36	6.36	6.53	6.65	6.61	—	—	—	—	—	—
(IB)n/T7	4.90	4.78	10.4	8.81	8.07	6.52	7.35	6.91	6.57	6.94	6.67	6.69	7.02	6.92	6.81	—	—	—	—	—	—
DS, %	1.61	2.01	1.85	1.46	1.09	1.01	0.97	0.89	1.09	0.99	1.26	1.44	1.26	0.96	0.69	12.1	3.8	2.4	3.6	2.6	1.1
DIV, %	0.42	0.44	0.57	0.53	0.38	0.34	1.50	0.57	0.89	0.37	0.37	0.74	0.84	0.96	0.69		1.3	0.9	1.5	0.7	1.7
IFDU, %	—	7.8	7.8	8.1	8.1	7.9	5.9	6.5	5.9	11.4	5.9	11.2	—	—	—						

TABLE IV

EX.-ITEM	6-7	6-8	6-9	6-10	7-1	7-2	7-3	7-4	7-5	7-6	7-7	7-8	7-9	7-10	7-11	8-1	8-2	8-3	9-1	9-2	9-3
POLYMER																					
LRV	21.1	→	→	→	→	→	→	→	→	→	→	→	→	→	→	15.7	→	→	21.9	→	→
TiO2, %	0.3	→	→	→	.035	→	→	→	→	→	→	→	→	→	→	→	→	→	.5	→	→
FIL/YARN																					
dpf	.42	→	→	→	.90	1.15	.81	.81	.81	.84	.84	.85	.81	.85	.81	.86	.76	.78	.5	→	→
# Fils	100	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Yarn Denier	42	→	→	→	90	115	80.9	81.2	80.8	80.5	81.2	84.7	81.2	84.5	81.2	85.6	76.0	78.1	50	→	→
EXTRUSION																					
TP, °C	293	296	291	→	288	290	288	288	292	287	—	—	290	287	292	294	294	285	289	291	293
P/Ro, cm^-2	4.2	→	→	→	4.2	→	→	→	→	→	→	→	→	→	→	→	→	→	4.2	→	→
w, g/min	.141	→	→	→	.215	.275	.247	.272	.272	.213	.233	.259	.247	.276	.272	.210	.208	.238	.218	.239	.254
q, cm^3/gm	.115	→	→	→	.166	.225	.208	.223	.223	.175	.191	.212	.208	.227	.223	.172	.171	.195	.169	.184	.208
tr, min	4.26	→	→	→	2.95	2.18	2.36	2.20	2.20	2.80	2.56	2.31	2.36	2.16	2.20	2.85	2.84	2.51	2.90	2.66	2.36
L, mils	36	→	→	→	50	→	→	→	→	36	→	→	→	→	→	→	→	→	50	→	→
L, cm x10	.914	→	→	→	1.27	→	→	→	→	.914	→	→	→	→	→	→	→	→	1.27	→	→
DRND, mils	9	→	→	→	12	→	→	→	→	9	→	→	→	→	→	→	→	→	12	→	→
DRND, cm x10	.299	→	→	→	.305	→	→	→	→	.229	→	→	→	→	→	→	→	→	.305	→	→
L/DRND	4	→	→	→	4.17	→	→	→	→	4	→	→	→	→	→	→	→	→	4.17	→	→
RC, mils^2	63.6	→	→	→	113.1	→	→	→	→	63.6	→	→	→	→	→	→	→	→	113.1	→	→
RC, mm^2 x10^3	.411	→	→	→	.730	→	→	→	→	.411	→	→	→	→	→	→	→	→	.730	→	→
Go, sec^-1	1643	→	→	→	1056	1350	1213	1336	1336	2481	2714	3017	2878	3215	3169	2447	2423	2273	1070	1166	1247
(L/DRND)Go x10^-1	6571	→	→	→	440	563	506	557	557	993	1086	1207	1151	1286	1268	979	969	1109	442	487	521
k(L/DRND)Go, °C	13.1	→	→	→	0.9	1.1	1.0	1.1	1.1	2.0	2.2	2.4	2.3	2.6	2.6	1.9	1.9	2.2	0.9	0.9	1.0
QUENCHING																					
LDQ, cm	2.9	→	→	→	6.7	→	→	→	→	→	→	→	→	→	→	7.1	→	→	6.7	→	→
12)dpf, cm	7.8	→	→	→	11.4	12.9	10.8	→	→	11.0	11.0	11.1	11.1	11.1	10.8	11.1	10.5	10.6	10.0	→	→
Vo, m/min	16.3	→	→	→	—	—	—	—	—	—	—	—	—	—	—	25	→	25	30.6	→	→
Lc, cm	109	→	97	81	137	147	131	→	→	132	133	133	131	133	131	109	128	109	100	→	→
50+90)dpf, cm	109	→	→	→	135	147	→	→	→	→	→	→	→	→	→	133	129	→	114	→	→
SPINNING																					
V, y/min	3300	→	→	→	2350	2350	3000	3300	3300	2500	2700	3000	3000	3200	3300	2400	2700	3000	4300	4700	5000
V, m/min	3018	→	→	→	2149	2149	2743	3018	3018	2286	2469	2743	2743	2926	3018	2195	2468	2743	3932	4298	4570
ER(=V/Vo)	1073	→	→	→	890	697	989	—	—	537	537	530	556	530	556	524	593	586	1602	—	—
Ea [=ln(ER)]	6.98	→	→	→	6.79	6.55	6.90	6.49	7.31	6.29	6.29	6.27	6.56	6.27	6.56	6.26	6.39	6.37	7.38	—	—
Ea×I7, g/d	—	—	—	—	4.63	8.82	5.93	—	—	4.91	5.22	5.70	5.32	6.08	5.64	3.88	4.92	4.97	10.1	9.74	11.1
YARN																					
T7, g/d	—	—	—	—	0.69	0.43	0.86	0.94	1.06	0.78	0.83	0.91	0.81	0.97	0.86	0.62	0.77	0.78	1.37	1.32	1.51
EB, %	—	—	—	—	120.6	132.8	94.3	93.7	73.8	121.6	116.8	108.5	98.5	102.8	93.3	127.8	113.	102.3	67.1	69.5	66.4
I, g/d	—	—	—	—	2.51	2.00	2.49	2.87	2.13	2.70	2.88	2.94	2.60	2.98	2.30	1.81	1.88	1.89	3.19	3.28	3.14
T0, g/d	—	—	—	—	5.55	4.66	4.83	5.57	3.71	5.99	6.25	6.14	5.17	6.05	4.44	4.13	4.00	3.82	5.33	5.56	5.22
(IB)N, g/d	—	—	—	—	5.47	4.59	4.76	5.49	3.65	5.90	6.16	6.05	5.09	5.96	4.33	5.54	5.36	5.12	4.58	4.78	4.49
(IB)×/T7	—	—	—	—	7.9	10.7	5.5	5.8	3.4	7.6	7.4	6.6	6.3	6.1	8.9	8.9	7.0	6.6	3.35	3.62	3.03
DS, %	3.8	3.8	3.3	3.1	—	9.9	9.9	4.3	5.0	14.2	8.4	2.4	9.1	1.7	4.95	2.33	3.47	2.33	1.42	1.34	1.29
DIV, %	1.7	1.9	1.3	1.0	—	—	—	—	—	1.70	1.19	0.44	—	0.33	—	0.81	0.75	0.63	.41	.36	.23

TABLE V

EX.-ITEM	9-4	9-5	9-6	9-7	9-8	9-9	9-10	9-11	10-1	10-2	10-3	10-4	10-5	10-6	10-7	10-8	10-9	10-10	10-11	10-12	10-13
POLYMER																					
LRV	21.9	→	→	→	→	→	→	→	21.9	→	→	→	→	→	→	→	→	→	→	→	→
TiO_2,%	0.3	→	→	→	→	→	→	→	0.7	→	→	→	→	→	→	→	→	→	→	→	→
FIL/YARN																					
dpf	0.5	→	→	→	→	→	→	→	0.7	→	→	→	→	→	→	→	→	→	→	→	→
#Fils	100	→	→	→	→	→	→	→	100	→	→	→	→	→	→	→	→	→	→	→	→
Yarn Denier	50	→	→	→	→	→	→	→	70	→	→	→	→	→	→	→	→	→	→	→	→
EXTRUSION																					
TP, °C	290	292	292	293	290	290	290	297	286				294	294			286	286	294	286	286
A/Ro, cm^2	4.2								4.2												
w, g/min	.171	.218	.239	.254	.171	.218	.239	.254	.334								.355			.334	
q, cm^3/min	.132	.169	.184	.208	.132	.169	.184	.208	.258								.291			.258	
tr, min	3.71	2.90	2.66	2.36	3.71	2.90	2.66	2.36	1.90								1.68			1.9	
L, mils	36				18				36									50			
L, cm x10	.914				.456				.914									1.27			
DRND, mils	9				6				9									12			
DRND, cm x10	.229				.152				.229									.305			
L/DRND	4				3				4									4.17			
RC, mil^2	63.6				28.3				63.6									113.1			
RC, cm^2x10^3	.411				.182				.411									.730			
Go, sec^{-1}	1992	2540	2784	2959	6722	8570	9395	9985	3891								4136	1743		1640	
(L/DRND)Go·10^{-1}	397	1016	1114	1184	2017	2571	2819	2995	1556								1654	727		684	
k(L/DRND)Go, °C	0.8	2.0	2.2	2.3	4.0	5.5	5.6	6.0	3.1								3.3	1.4		1.3	
QUENCHING																					
LDQ, cm	6.7								8.5									10.0			
121dpf, cm	10.0								11.3	21.3	30.6	21.3	30.6	21.3		30.6	21.3				
Va, m/min	30.6										→	61	→	109	61	61	109				
LC, cm	100								125									125			
50x90ldpf, cm	114																				
SPINNING																					
V, y/min	4100	4300	4700	5000	4100	4300	4700	5000	4700								5000	5000		4700	
V, m/min	3749	3932	4298	4570	3749	3932	4298	4572	4298								4572	4572		4298	
ER(=V/Va)	1602	901			401				644								644	1145			
Ea [=ln(ER)]	7.38	6.80		11.0	5.99				6.47								6.47	7.04		8.66	
Eanl7, g/d	9.08	8.77	11.0	11.0	5.63	8.03	7.85	8.81	7.70	7.81	8.22	8.09	8.35	7.18	7.44	7.44	7.89	8.10	8.88	8.66	7.74
YARN																					
S, z	3.7	3.3	3.7	3.2	4.9	3.8	3.9	4.3	3.3	3.1	3.0	2.9	3.0	3.4	3.1	3.1	3.1	3.2	3.4	3.1	3.5
Mi, z	42.1	39.4	42.7	46.1	35.1	47.1	45.0	50.9	44.2	50.7	47.1	45.3	44.6	45.2	47.1	39.5	48.6	41.4	48.5	48.7	42.6
T7, g/d	1.23	1.29	1.61	1.62	0.94	1.34	1.31	1.47	1.19	1.16	1.27	1.25	1.29	1.11	1.15	1.15	1.22	1.15	1.12	1.23	1.10
EB, z	72.9	72.8	53.1	62.8	76.4	64.3	67.9	62.7	77.5	76.8	71.7	71.9	68.1	77.3	75.8	74.6	74.3	78.0	78.0	75.2	83.0
T, g/d	3.18	3.31	2.96	3.21	3.05	3.12	3.28	3.31	3.41	3.40	3.28	3.37	3.24	3.51	3.50	3.43	3.55	3.53	3.58	3.47	3.47
IB, g/d	5.50	5.70	4.53	5.23	5.28	5.13	5.51	5.39	6.05	6.01	5.63	5.79	5.45	6.15	5.99	5.99	6.19	6.28	6.37	6.35	6.08
(IB)n, g/d	4.95	5.64	4.08	4.71	4.75	5.62	4.96	4.85	5.87	5.83	5.46	5.62	5.23	6.03	5.97	5.05	6.00	6.09	6.18	6.16	5.90
(TB)n, g/d	4.02	4.37	2.53	2.90	5.05	4.19	3.78	3.29	4.93	5.02	4.29	4.49	4.10	5.43	5.19	5.05	4.91	5.29	5.51	5.00	5.36
(TB)n/l7	1.40	1.30	1.31	1.58	1.47	1.49	1.54	1.38	1.67	1.96	1.29	1.46	1.13	1.34	1.23	1.16	1.32	1.23	1.86	1.77	2.24
DS,z	.52	.36	.23	.25	.47	.31	.40	.33	.43	.73	.37	.36	.22	.48	.26	.21	.67	.52	.42	.45	.45
DIU, z																					

TABLE VI

EX.-ITEM	10-14	10-15	13-1	13-2	13-3	13-4	13-5	13-6	13-7	13-8	13-9	13-10	15-1	15-2	15-3	15-4	15-5	16-1	17-1	17-2
POLYMER																				
LRV	21.9	→	20.8	→	→	→	→	→	→	→	→	→	21.2	→	→	→	→	→	→	→
TiO2,%	0.3	→											0.035							
FIL/YARN																				
dpf	0.7	→	0.5	→	→	→	→	0.7	→	→	→	→	.85	.59	.50	.45	.38	.82	.85	.86
# Fils	100	→	50	→	→	→	→	→	→	→	→	→	68	200	200	168	200	100	50	50
Yarn Denier	70	→	50	→	→	→	→	70	→	→	→	→	58	118	100	75.6	76	82	43	43
EXTRUSION																				
TP, °C	294	286	293	→	→	→	→	→	→	→	→	→	290	294	294	294	294	285	290	290
#/Ro, cm^-2	4.2	→																		
w, g/min	.306	→	.229	.239	.249	.259	.269	.321	.335	.349	.363	.377	.207	.144	.224	.201	.093	.196	.306	.394
q, cm^3/min	.251	→	.188	.196	.204	.213	.221	.263	.275	.286	.298	.309	.170	.119	.184	.165	.076	.161	.250	.324
tr, min	1.95	→	2.61	2.50	2.4	2.3	2.22	1.86	1.79	1.71	1.64	1.58	4.22	3.19	2.06	2.74	4.99	3.03	3.90	3.01
L, mils	50	→	36																	
L, cm x10	1.27	→	.914	→	→	→	→	→	→	→	→	→	1.27	.914			.657	.914	1.03	
DRND, mils	12	→	9										9				6	9	15	
DRND, cm x10	.305	→	.229										.229		.152		.152	.229	.381	
L/DRND	4.17	→	4	→	→	→	→	→	→	→	→	→	5.6	4			3	4	4.8	
RC, mil^2	113.1	→	63.6	→	→	→	→	→	→	→	→	→	63.6				28.3	63.6	176.6	
RC,cm^2x10^3	.730	→	.411	→	→	→	→	→	→	→	→	→	.411				.182	.411	1.141	
Go, sec^-1	1502	→	2668	2784	2901	3017	3134	3735	3836	4061	4224	4388	3349	1676	2602	2343	3543	2282	230	991
(L/DRND)Go x10^-1	627	→	1067	1114	1160	1207	1254	1494	1534	1625	1690	1755	1875	670	1041	937	1093	912	110	476
K(L/DRND)Go, °C	1.2	→	2.1	2.2	2.3	2.4	2.5	3.0	3.1	3.2	3.4	3.5	3.8	1.4	2.1	1.9	2.2	1.8	0.2	1.0
QUENCHING																				
LDQ, cm	6.7	→	5.7	→	→	→	→	10.0	→	→	→	→	6.7	2.9	8.5	8.0	7.4	10.9	11.1	11.1
122dpf, cm	10.0	→	8.5	→	→	→	→	→	→	→	→	→	11.0	9.2						
Vo, m/min	21.3	→	10.5	→	→	→	→	→	→	→	→	→	16	30			16	22	13	13
Lc, cm	109	→	81	→	→	→	→	→	→	→	→	→	103							
50x90Jdpf, cm	125	→	114	→	→	→	→	125	→	→	→	→	133	119	114	110	105	131	133	133
SPINNING																				
V, y/min	4300	→	4500	4700	4900	5100	5300	4500	4700	4900	5100	5300	2400	2400	4400	4400	2400	2350	3500	4500
V, m/min	3932	→	4115	4298	4481	4633	4846	4115	4298	4481	4633	4846	2195	2195	4023	4023	2195	2149	3200	4115
ER(=V/Vo)	1145	→	901	→	→	→	→	644	→	→	→	→	530	764	901	1001	1527	550	2911	2911
ε a [=ln(ER)]	7.04	→	6.80	8.36	8.98	9.52	10.1	6.47	6.92	7.44	7.89	8.54	6.27	6.64	6.80	6.91	6.27	6.31	7.98	7.98
CosT7, g/d	6.97	6.69	8.36	→	→	→	→	6.66	→	→	→	→		4.78	9.86	→	→	6.37	7.02	12.0
YARN																				
S, %	3.5	3.6	—	3.2	4.0	4.0	3.2	3.5	4.5	3.5	3.4	4.0	—	2.8	3.4	—	—	2.5	4.3	5.10
Mi, g/d	45.7	36.4	—	—	—	—	—	—	—	—	—	—	144.9	126.6	82.8	86.5	121.8	92.9	90.0	46.0
T7, g/d	0.99	0.95	1.23	1.23	1.32	1.40	1.49	1.03	1.07	1.15	1.22	1.32	2.88	.72	1.45	1.34	—	1.01	0.88	1.50
EB, %	84.8	89.1	52.1	58.7	53.6	47.5	45.5	66.8	69.4	67.5	56.3	54.8	7.05	126.6	82.8	86.5	121.8	92.9	90.0	46.0
I, g/d	3.45	3.37	2.73	2.84	2.82	2.71	2.70	2.88	3.04	3.13	2.91	2.93	2.88	2.97	3.12	3.22	3.23	2.40	3.00	2.65
TB, g/d	6.35	6.38	4.37	4.15	4.51	4.33	4.00	3.93	5.15	5.24	4.55	4.54	7.05	6.72	5.70	6.01	7.16	4.64	5.70	3.87
(TB)n, g/d	6.16	6.19	4.41	4.19	4.56	4.37	4.04	3.97	5.20	5.29	4.60	4.59	6.98	6.66	3.89	5.64	7.09	4.54	5.64	3.83
(TB)n/T7	6.22	6.51	3.58	3.40	3.45	3.12	2.71	3.85	4.85	4.60	3.77	3.47	—	9.25	2.68	4.21	—	4.50	6.41	2.55
DS, %	1.68	1.87	3.85	1.20	1.23	1.21	1.04	1.00	0.97	0.90	2.90	2.90	4.26	—	—	—	—	—	—	—
DIV, %	0.38	0.71	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE VII

EX.-ITEM	XI-1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PROCESS																		
Type	MD	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Speed, rpm	600	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Draw Temp., °C	COLD	→	→	155	→	→	COLD	→	→	155	→	→	COLD	→	→	155	→	→
Set Temp., °C																		
Draw Ratio	1.45	1.50	1.55	1.45	1.50	1.55	1.45	1.50	1.55	1.45	1.50	1.55	1.45	1.50	1.55	1.45	1.50	1.55
YARN																		
# fils	100																	
Denier	58.4	56.2	54.7	50.6	56.7	55.0	53.2	51.4	50.3	53.5	51.8	49.8	48.3	46.7	45.5	48.6	47.1	46.1
S, Z	4.8	4.7	5.3	5.9	5.5	5.7	4.6	4.6	4.5	5.6	5.2	5.5	4.7	4.3	4.5	5.0	5.2	5.3
MOD., g/d	82.7	89.4	93.9	86.7	90.4	95.2	91.0	96.1	100.5	89.9	93.5	99.2	94.7	97.4	99.3	90.5	96.8	99.4
T7, g/d	3.2	3.7	4.1	3.2	3.7	4.1	3.4	3.9	4.3	3.4	3.9	4.4	3.6	4.0	4.4	3.6	4.0	4.4
EB, Z	33.7	28.8	25.7	35.3	31.2	25.8	34.0	26.5	22.6	32.6	28.2	24.0	30.8	27.0	22.8	30.8	25.5	22.5
T, g/d	4.9	5.1	5.3	4.9	5.1	5.2	5.0	5.1	5.3	4.8	5.1	5.3	5.2	5.2	5.3	4.9	5.0	5.2
DS, Z	1.8	1.7	1.9	2.0	1.9	1.9	1.8	1.9	1.8	2.0	2.7	2.1	2.2	2.2	2.2	2.2	2.2	2.3
Uster, Z	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.7

TABLE VIII

EX.-ITEM	XII-1	2	3	4	5	6	XIV-1	2	3	4	5	6	7	8	XVIII-1	2	3
PROCESS																	
Type	MD	→	→	→	→	→	AJT	→	→	→	→	→	→	→	MD	→	→
Speed, rpm	600	→	→	→	→	→	300	→	→	→	→	→	→	→	600	→	→
Draw Temp., °C	COLD	→	→	→	→	→											
Draw Ratio	1.69	1.57	1.44	1.42	1.42	1.42	1.0	1.1	1.2	1.32	1.0	1.1	1.2	1.32	1.42	→	→
YARN																	
# fils	100						100								50		
Denier	35.9	35.6	35.4	35.9	36.1	36.1	91.4	95.0	85.8	77.3	81.8	75.1	70.4	64.7	35.9	36.1	36.1
Bulk, Z	NA	→	→	→	→	→	1.4	11.8	11.4	12.0	12.1	13.1	15.7	17.0	NA	→	→
S, Z	3.9	4.2	4.4	4.0	4.0	4.9	3.5	4.3	8.2	12.7	3.4	4.9	8.2	11.8	4.0	4.0	4.9
DHS, Z	---						2.8	4.1	7.6	11.0	3.2	4.4	7.1	10.4	---		
T7, g/d	3.97	3.84	3.56	3.54	3.54	3.49	---								3.54	3.54	3.49
EB, Z	23.2	24.4	26.7	27.2	27.2	28.6	61.1	57.1	41.3	27.2	64.4	60.9	43.3	29.6	26.7	27.2	28.6
T, g/d	5.23	4.96	4.54	4.50	4.50	4.50	1.96	2.22	2.42	2.64	2.12	2.46	2.58	2.78	4.56	4.50	4.50
DS, Z	1.9	1.8	2.0	2.1	2.1	2.4	NA	→	→	→	→	→	→	→	2.1	2.1	2.4
Uster, Z	---						NA	→	→	→	→	→	→	→	---		

We Claim:

1. A process for preparing spin-oriented polyester fine filaments of denier in the range of about 1 to about 0.2, wherein,

5   (i) the polyester polymer is selected to have a relative viscosity (LRV) in the range of about 13 to about 23, a zero-shear melting point (T_M^o) in the range about 240°C to about 265°C, and a glass-transition temperature (T_g) in the range of about 40°C

10   to about 80°C;

(ii) said polyester is melted and heated to a temperature (T_p) in the range about 25°C to about 55°C above the apparent polymer melting point $(T_M)_a$;

(iii) resulting melt is filtered sufficiently

15   rapidly that the residence time (t_r) is less than about 4 minutes;

(iv) the filtered melt is extruded through a spinneret capillary at a mass flow rate (w) in the range about 0.07 to about 0.7 grams per minute, and the

20   capillary is selected to have a cross-sectional area (A_c) in the range about 125×10^{-6} cm^2 to about 1250×10^{-6} cm^2, and a length (L) and diameter (D_{RND}) such that the (L/D_{RND})-ratio is at least about 1.25 and less than about 6.

25   (v) protecting the extruded melt from direct cooling as it emerges from the spinneret capillary over a distance (L_{DQ}) of at least about 2 cm and less than about $(12dpf^{\frac{1}{2}})$cm, where dpf is the denier per filament of the fine spin-oriented polyester filament,

30   (vi) cooling the extruded melt to below the polymer glass-transition temperature (T_g) and

attenuating to an apparent spinline strain (ε_a) in the
range of about 5.7 to about 7.6, and to an apparent
internal spinline stress (σ_a) in the range of about
0.045 to about 0.195 g/d,

5   (vii) then converging the cooled filaments
into a multifilament bundle by use of a low friction
surface at a distance (L_c) in the range about 50 cm to
about 140 cm, and

           (viii) winding up the multifilament bundle at
10   a withdrawal speed (V) in the range of about 2 to about
6 km/min.

           2.   A process according to claim 1, wherein,
said polyester contains in the range of about 1 to
about 3 mole percent of ethylene 5-M-sulfo-
15   isophthalate, wherein M is an alkali metal cation.

           3.   A process according to claim 1, wherein,
said polyester is essentially poly(ethylene
terephthalate), composed of first alternating
hydrocarbolenedioxy structural units A [$-O-C_2H_4-O-$],
20   and hydrocarbolenedicarbonyl structural units B [$-(O)C-$
$C_6H_4-C(O)-$], modified with minor amounts of other
hydrocarbolenedioxy structural units A and/or
hydrocarbolenedicarbonyl structural units B that differ
from the first alternating hydrocarbolenedioxy
25   structural units A and hydrocarbolenedicarbonyl
structural units B, such as to provide a polyester
polymer with a zero-shear melting point (T_M^o) in the
range about 240°C to about 265°C and a glass-transition
temperature (T_g) in the range about 40°C to about 80°C.

30   4.   A process according to claim 1, wherein,
the apparent spinline strain (ε_a) is in the range about
6 to about 7.3, and the apparent internal spinline
stress (σ_a) is controlled to obtain an average

orientation as represented by a tenacity-at-7%-
elongation (T_7) in the range of about 0.5 to about 1.75
g/d.

5   5.   A process according to any one of the
claims 1 through 4, wherein, the polymer temperature
(T_p) is in the range of about 30°C to about 50°C above
the apparent polymer melting point $(T_M)_a$, the spinneret
capillary cross-section area (A_c) is in the range about
$125x10^{-6}$ cm^2 to about $750x10^{-6}$ cm^2, the extrusion
10   filament density ($\#_c/A_o$) is in the range about 2.5 to
about 25 filaments per cm^2; and said cooling of the
extruded melt is by use of radially directed air having
a temperature (T_a) less than about the polymer glass-
transition temperature (T_g) and a velocity (V_a) in the
15   range about 10 to about 30 m/min, and said convergence
is by a metered finish tip guide at a distance (L_c) in
the range about 50 cm to about (50+90dpf½)cm, and the
withdrawal speed (V) is in the range about 2 to about 5
km/min.

20   6.   A process according to any one of the
claims 1 through 4, wherein, the filaments have a
denier in the range of about 0.6 to about 0.2 and a
denier spread (DS) less than about 2%.

          7.   Spin-oriented polyester filaments of
25   fineness in the range of about 1 to 0.2 denier per
filament, wherein, said polyester is characterized by
having a relative viscosity (LRV) in the range of about
13 to about 23, a zero-shear polymer melting point
(T_M^o) in the range about 240°C to about 265°C, and a
30   polymer glass transition temperature (T_g) in the range
of about 40°C to about 80°C; and said fine filaments
are further characterized by:

          (i) boil-off shrinkage (S) less than about

the maximum shrinkage potential (S_m), wherein $S_m = [(550 - E_B)/6.5]$,% and the percent elongation-to-break (E_B) is in the range of about 40% to about 160%,

(ii) a maximum shrinkage tension, (ST_{max}), in
5   the range about 0.05 to about 0.2 g/d, with a peak
temperature $T(ST_{max})$, in the range about 5°C to about
30°C above the polymer glass-transition temperature
(T_g);

(iii) tenacity-at-7%-elongation (T_7) in the
10   range of about 0.5 to about 1.75 g/d, such that the
$[(T_B)_n/T_7]$-ratio is at least about $(5/T_7)$, wherein,
$(T_B)_n$ is the normalized tenacity-at-break, and the
elongation-at-break (E_B) is in the range of about 40%
to about 160%;

15   (iv) an average along-end denier spread (DS)
of less than about 4%.

8. Filaments according to claim 7, such as
are especially suitable for use as draw feed yarns,
characterized by a boil-off shrinkage (S) and dry heat
20   shrinkage (DHS) at least about 12%, an elongation-at-
break (E_B) in the range of about 80% to about 160%, and
a tenacity-at-7%-elongation (T_7) in the range of about
0.5 to about 1 g/d.

9. Filaments according to claim 7, such as
25   are especially suitable for use as direct-use textile
yarns, are characterized by a shrinkage differential
(ΔS) less than about +2%, wherein, boil-off shrinkage
(S) and dry heat shrinkage (DHS) are in the range of
about 2% to about 12%, such that the filament denier
30   after shrinkage, is less than about 1; and a T_7 in the
range about 1 to about 1.75 g/d, an (E_B) in the range
about 40% to about 90%, and a post-yield modulus (M_{py})
in the range about 2 to about 12 g/d;

10.   Filaments according to claim 7 having
the capability of being uniformly cold drawn,
characterized by a shrinkage differential (ΔS) less
than about +2%, wherein, boil-off shrinkage (S) and dry

5   heat shrinkage (DHS) are in the range of about 2% to
about 12%, an onset of cold crystallization, T_{CC}(DSC),
of less than about 105°C and an instantaneous tensile
modulus at least about 0.

11.   Drawn spin-oriented polyester filaments
10   with deniers after boil-off shrinkage, dpf(ABO) in the
range of about 1 to about 0.2 dpf, wherein, said
polyester is characterized by having a relative
viscosity (LRV) in the range of about 13 to about 23, a
zero-shear polymer melting point (T_M^O) in the range of
15   about 240°C to about 265°C, and a polymer glass-
transition temperature (T_g) in the range of about 40°C
to about 80°C; and said drawn filaments are further
characterized by:

(i) boil-off shrinkage (S) and dry heat
20   shrinkage (DHS) in the range of about 2% to about 12%;

(ii) tenacity-at-7%-elongation (T_7) at least
about 1 g/d, such that the $[(T_B)_n/T_7]$-ratio is at least
about $(5/T_7)$, wherein $(T_B)_n$ is the normalized tenacity-
at-break and the elongation-at-break (E_B) is in the
25   range of about 15% to about 55%;

(iii) the post-yield modulus (M_{py}) in the
range about 5 to about 25 g/d;

(iv) an average along-end denier spread (DS)
less than about 4%.

30   12.   Bulked spin-oriented polyester filaments
of fineness in the range of about 1 to about 0.2 dpf
(after boil-off shrinkage), wherein, said polyester is

characterized by having a relative viscosity (LRV) in
the range of about 13 to about 23, a zero-shear polymer
melting point ($T_M{}^o$) in the range of about 240°C to
about 265°C, and a polymer glass-transition temperature

5   (T_g) in the range of about 40°C to about 80°C; and said
filaments are further characterized by:

(i) boil-off shrinkage (S) and dry heat
shrinkage (DHS) in the range of about 2% to about 12%;

(ii) tenacity-at-7%-elongation (T_7) at least

10 about 1 g/d and an elongation-at-break (E_B) in the
range about 15% to about 55%, with a post-yield modulus
(M_{py}) in the range about 5 to about 25 g/d.

13. Filaments according to Claim 11 or 12,
wherein, the filaments are further characterized by a

15 dynamic loss modulus peak temperature $T(E''_{max})$ of less
than about 115° C.

14. Filaments according to Claims 11 or 12,
wherein the filaments are further characterized by a
relative disperse dye rate (RDDR) of at least about

20 0.1.

15. Filaments according to any one of Claims
7 to 6, wherein, the filaments have a shape factor (SF)
at least about 1.25.

16. Filaments according to any one of Claims

25 7 to 6, wherein the filaments have a denier in range of
about 0.6 to about 0.2 dpf.

17. Filaments according to any of Claims 7
to 6, wherein, the filaments have an along-end denier
spread (DS) less than about 2%.

30   18. Filaments according to any one of Claims
7 to 6, wherein, said polyester fiber contains in the

range of about 1 to about 3 mole % of 5-ethylene-M-
sulfo-isophthalate structural units, wherein, M is an
alkali metal cation.

      19.   Filaments according to any one of claims
5   7 to 12, wherein, said polyester is essentially
    poly(ethylene terephthalate), composed of first
    alternating hydrocarbolenedioxy structural units A,
    [-O-C$_2$H$_4$-O-], and hydrocarbolenedicarbonyl structural
    units B, [-C(O)-C$_6$H$_4$-C(O)-], modified with minor
10 amounts of other hydrocarbolenedioxy structural units A
    and/or hydrocarbolenedicarbonyl structural units B,
    that differ from said first alternating
    hydrocarbolenedioxy structural units A and
    hydrocarbolenedicarbonyl structural units B, such as to
15 provide a polyester polymer with a zero-shear melting
    point (T$_M$^{O}) in the range about 240°C to about 265°C and
    a polymer glass-transition temperature (T$_g$) between
    about 40°C and about 80°C.

FIG.1

FIG.2

$$SOC = \left(\frac{\triangle n}{\sigma_a}\right) = 0.645 - 0.75 \, (g/d)^{-1}$$

FIG.3

FIG.4

FIG.5

STRESS
(g/d)

Tan β

Tan α

A

B

C

EXTENSION RATIO

FIG.6

POST YIELD
SECANT MODULUS
(Tan β),g/d

12
10
8
6
4
2
0

Tan β < Tan α

Tan β = Tan α

0   .020   .040   .060   .080   .100   .120   .140

BIREFRINGENCE (△n)

FIG.7

RELATIVE DISPERSE DYE RATE (RDDR)$_{1/2}$ %/(min)$^{1/2}$ (NORMALIZED TO 1 DPF)

BIREFRINGENCE ($\triangle$n)
(□ SPUN; ● DRAWN)

FIG.8

$V_{f,am} = CS^3 \cdot \left(\frac{1-X}{X}\right)\left(\frac{1-f_a}{f_a}\right)$ (Å)^3

DYNAMIC LOSS PEAK, T(E"$_{max}$),°C

FIG.9

FIG.10

FIG.11

SHRINKAGE
TENSION
(g/d)

TEMPERATURE (°C)

ST(max) @ T(STmax)

Tset (max)

FIG.12

TENACITY
(g/d)

ELONGATION (%)

FIG.13

$(T_B)n/(T_7)$

$[\text{TENACITY-AT-7\% ELONGATION}, T_7]^{-1}, (g/d)^{-1}$

10/10

FIG.14

(#FILS/BUNDLE) x (Dref/Dsprt)^2
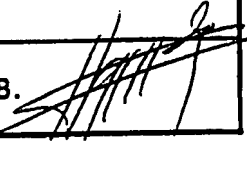
I. CLASSIFICATION OF SUBJECT MATTER   (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 D01F6/62

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	D01F ; D01D

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[°]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	PATENT ABSTRACTS OF JAPAN vol. 4, no. 101 (C-19)(583) 19 July 1980 & JP,A,55 062 209 (TORAY K.K.) 10 May 1980 see abstract ---	1-6
A	US,A,4 529 368 (MUNZER MAKANSI) 16 July 1985 see claims cited in the application ---	1
A	US,A,4 926 661 (BRIAN M. AGERS ET AL.) 22 May 1990 see claims cited in the application ---	1,5
A	US,A,4 134 882 (HANS R. E. FRANKFORT ET AL.) 16 January 1979 cited in the application ---	

-/--

° Special categories of cited documents :[10]

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
09 JUNE 1992	2 2. 06. 92

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	TARRIDA TORRELL J.B.

	III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)	
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
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A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 122 (C-488)(2969) 15 April 1988 & JP,A,62 243 824 (TEIJIN LTD) 24 October 1987 see abstract ---	

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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